DETROIT PUBLIC LIBRARY

JUL 3 1961

TECHNOLOGY
DEPARTMENT

Sm

The 'ENGLISH ELECTRIC' Journal

VOLUME SEVENTEEN · NUMBER TWO

JUNE 1961

With the compliments of

THE ENGLISH ELECTRIC CORPORATION.

750 THIRD AVENUE, NEW YORK 17, N.Y. *Telephone: MURRAY HILL 7-0303.*

Agents for Georgia, Alabama, Tennessee and South Carolina:

OSGOOD & ASSOCIATES, INC.,
988 Spring Street, N.W., P.O. Box 7383,
Station C, Atlanta, Georgia.

Agents for Massachusetts, Rhode Island, Maine, New Hampshire and Vermont:

FLAGG, BRACKETT & DURGIN, INC.,
183 Essex Street,
Boston 11, Massachusetts.

Agents for Southern Florida:

CHARLES R. LEE & ASSOCIATES, INC.,
3796 West Flagler Street,
Miami 44, Florida.

THE 'ENGLISH ELECTRIC' JOURNAL

VOLUME SEVENTEEN NUMBER TWO JUNE 1961

CONTENTS

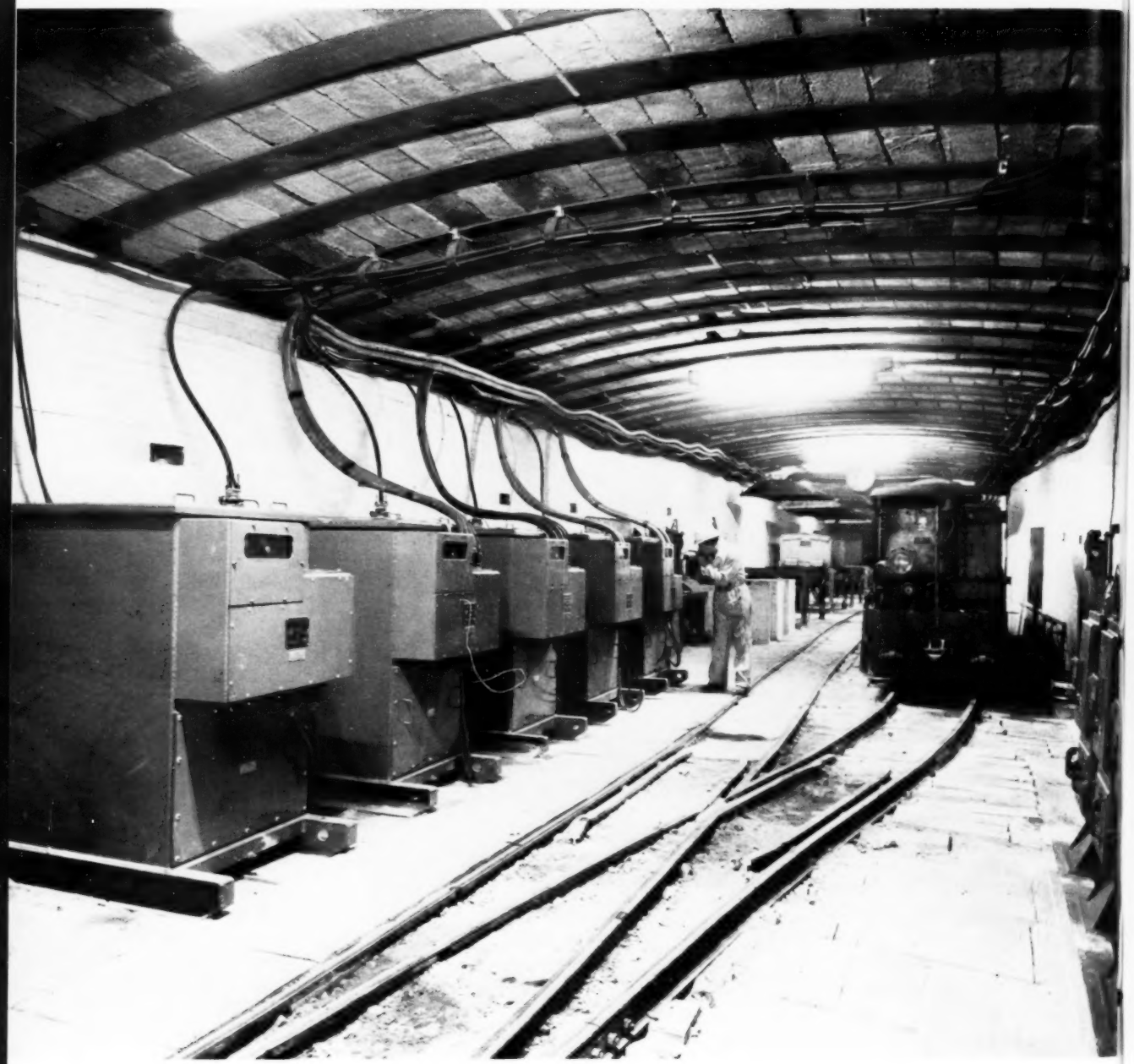
Page 4 : ELECTRICAL EQUIPMENT FOR A SHIP HYDRODYNAMICS LABORATORY, *by D. V. J. Leitch, A.M.I.E.E., Deputy Contracts Manager, Electrical Plant Division.*

16 : DISTRIBUTION OF ELECTRICITY ON BOARD SHIP, *by M. J. Bolton, A.C.T.(L'pool), A.M.I.E.E., A.I.Mar.E., Technical Assistant to the Superintendent Engineer, Cunard Steam Ship Company, (formerly of Fusegear Division, The English Electric Company).*

22 : RING-SPINNING FRAMES AT TULKETH SPINNING COMPANY, PRESTON.

31 : COMPUTERS AS AN AID TO ELECTRIC MINE WINDER DESIGN, *by F. Killoran, A.M.I.E.E., Mining Division.*

All communications respecting editorial contents should be addressed to the Editor, THE ENGLISH ELECTRIC JOURNAL, THE ENGLISH ELECTRIC COMPANY LIMITED, STAFFORD, ENGLAND.



MINE LOCOMOTIVE BATTERY CHARGING. *A battery-charging station in a West Midlands coal mine of the National Coal Board. On the left are the five 'English Electric' 25 kW charging units, each in a dust-tight case and comprising a naturally air-cooled silicon rectifier, a dry-type transformer, and automatic control gear. Within an eight-hour shift, one of these units will restore a fully discharged* 94 *or* 100*-cell lead acid battery of a* 12*-ton locomotive to its full capacity of* 405-530 *amperehours.* (Main contractors: Greenwood & Batley Limited.)

Editorial

THE ship hydrodynamics laboratory referred to in the first article of this issue is an instance of the research facilities being made available to keep U.K. shipbuilding to the forefront in what is now a seriously competitive industry. This new laboratory at Feltham supplements the facilities that were already in existence at the National Physical Laboratory at Teddington, nearby. As a matter of history, it was Dick Kerr & Company of Preston, one of the firms that later merged to become The English Electric Company, who built the towing carriage of the earlier of the two tanks at the Teddington laboratory. That was in 1911. On the other hand, the most recent such equipment supplied by 'English Electric' is the complete electrical system for a towing carriage at the Clydebank experimental tank of John Brown & Company. It was in this tank that the design data for such famous ships as the 'Lusitania', 'Aquitania' and the two 'Queen' liners was obtained.

The Company's contribution to the marine industry in quite another sphere, that of equipping actual vessels for service, is instanced by the second article of this issue, 'Distribution of electricity on board ship'—and also, as it happens, by two noteworthy orders recently received for marine propulsion machinery. These orders are for the design and manufacture of the main propulsion steam turbines and condensers for Britain's second nuclear submarine (the prototype shore-based turbines and condensers having already been built by the Company), and the 6,000s.hp. diesel-electric propulsion machinery for a new cable-laying ship.

Looking to the future of nuclear-powered vessels, the Company has entered into a licence agreement with the Atomics International Division of North American Aviation for the exchange of information on the technology of the organic reactor system. This system, in which Atomics International are the world's leading experts, is essentially simple and therefore particularly suited to marine use. 'English Electric' put forward a proposal based on it when selected as one of five companies to tender last July against a Ministry of Transport enquiry for a nuclear propulsion unit to power a 65,000 tons deadweight tanker.

500MW generating sets for Britain . . . . . and 150,000hp Kaplan turbines for Canada

AN outstanding order received by the Company since our last issue is from the Central Electricity Generating Board for four 500MW single-line turbo-alternator sets to be installed in the West Burton power station. The first of these sets is planned to be commissioned in 1965 and all four units are expected to be in service by the end of 1967.

A contract for three 150,000hp Kaplan turbines has been awarded by the Manitoba-Hydro-Electric Board to English Electric Canada, a division of John Inglis Company, Toronto. These machines, ranking among the most powerful Kaplans in the world, are expected to be in operation by 1964 at Grand Rapids generating station on the Saskatchewan River. Design studies and model testing will be carried out in the U.K. by The English Electric Company.

Electrical Equipment for a Ship Hydrodynamics Laboratory

by D. V. J. LEITCH, A.M.I.E.E., Deputy Contracts Manager, Electrical Plant Division

THIS ARTICLE describes the electrical equipment supplied by The English Electric Company in connection with the tank for testing ship models and the water tunnel for testing propellers and hydrofoils at the Ship Hydrodynamics Laboratory of the Department of Scientific and Industrial Research at Feltham in Middlesex. This laboratory is part of the Ship Division of the National Physical Laboratory. The 'English Electric' equipment comprises the main electrical drives with their associated switchgear and ancillaries.

THE SHIP MODEL TESTING TANK

The ship model testing tank consists of a waterway 1,300 ft long, 48 ft wide and 25 ft deep constructed in reinforced concrete. The carriage which tows the models (Fig. 2) runs on heavy rails laid on the tank walls on either side of this waterway, and is designed to tow a model weighing up to 5 tons, 40 ft long, at speeds up to 50 ft/sec. The rails on which it runs are levelled and aligned so that the track surfaces truly follow a line parallel with the earth's surface and are straight to within 0·005in over the complete length of the tank. The

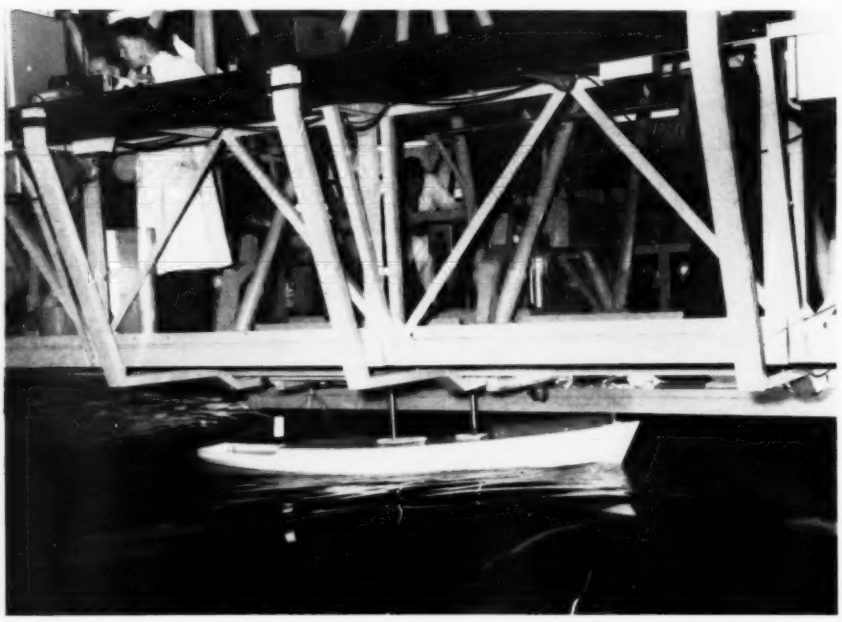


Fig. 1—A ship model being towed by the carriage shown in Fig. 2.

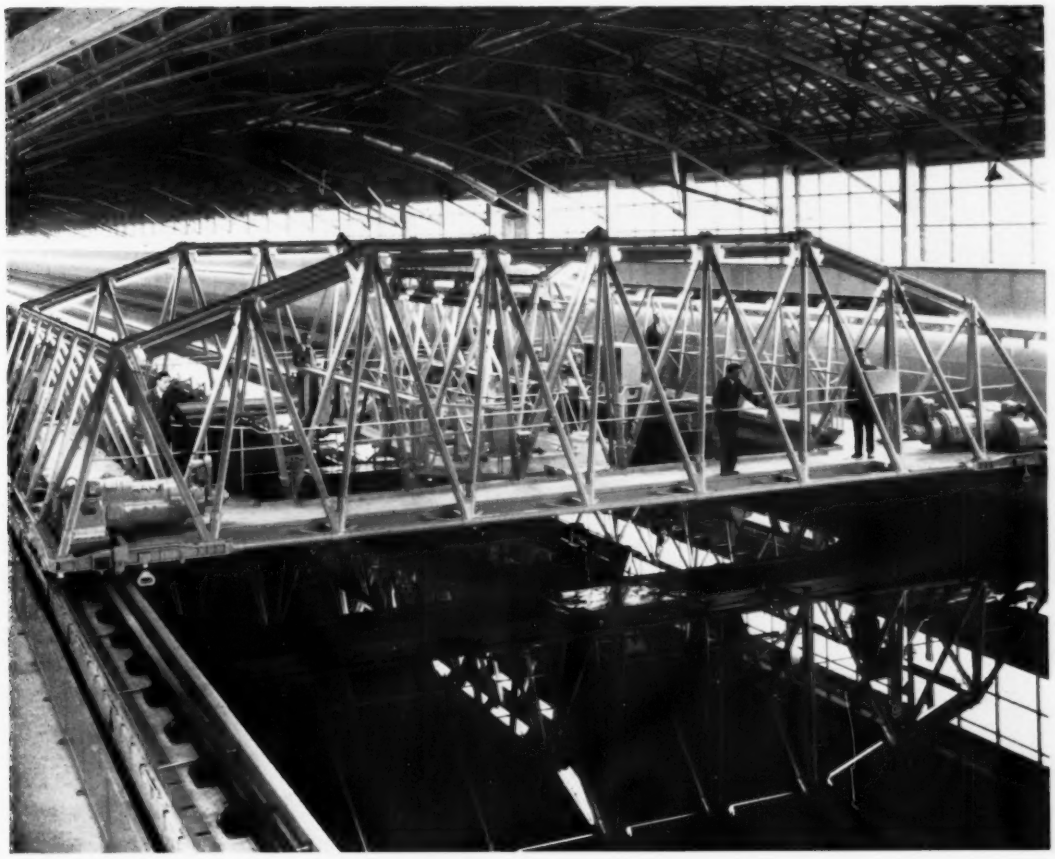


Fig. 2—The towing carriage on a return run from the end of the tank

carriage combines lightness with rigidity and consists of an open rectangle formed by tubular steel trusses of triangular form. These trusses are 50 ft long by 6 ft wide at base with heights up to 14 ft. A further member of similar form set within this frame carries dynamometer equipment by which the model is towed at predetermined constant speeds. Propulsion for the carriage is provided by four motors, each flange-mounted on twin-wheel bogies located at the corners (Fig. 4). Associated control gear is also mounted on the carriage (Fig. 3).

It is required that the actual speed of the carriage conform to the selected speed and remain sensibly constant over the test run within a tolerance of 0·1% of the selected speed. Further, the speed of any repeated runs must conform to the original selected speed within a tolerance of 0·5%.

Acceleration is limited normally by the need to avoid wheel slip and give a smooth take off, but facilities for other rates of acceleration are provided. The carriage is normally brought to rest by regenerative braking, followed by the application of servo-operated friction brakes to braking rails which run the length of the tank at each side.

The tank length was optimised to provide a sufficient testing period at the maximum speed of 50 ft/sec. At this condition the acceleration and deceleration periods are most significant.

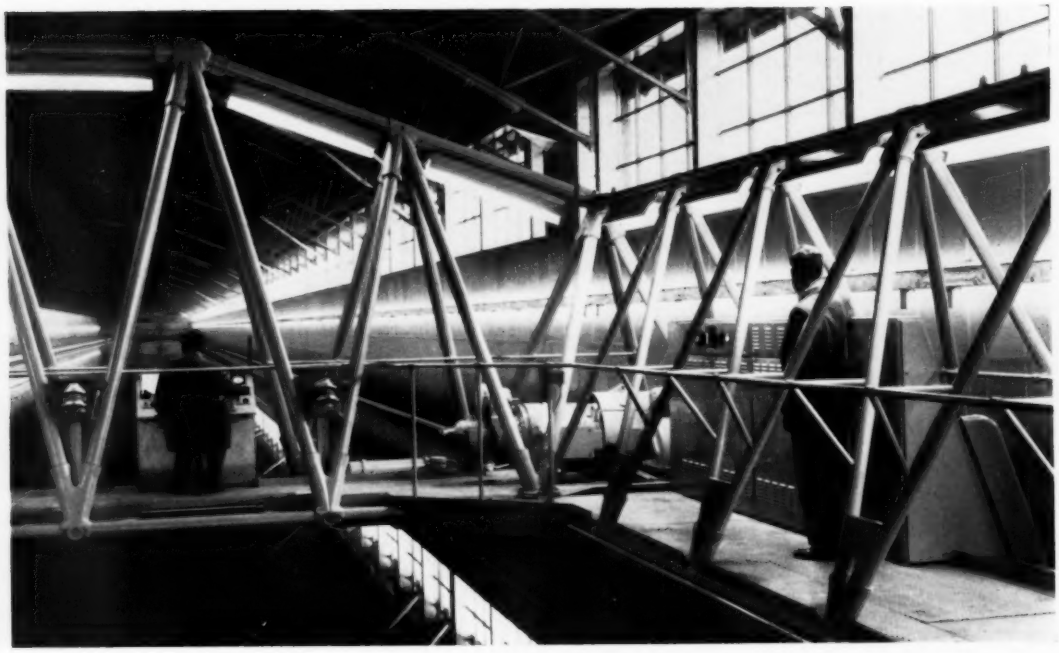


Fig. 3—A corner of the towing carriage, showing the control desk (left), one of the bogie motors, and one of the two groups of control cubicles

As the testing speeds are lowered these two factors become less important.

The principal features required of the electrical drive are to accelerate the carriage with constant torque of a value below that which induces wheel slip, and, when the pre-set speed is reached, to automatically reduce the torque to a value necessary to overcome tractive effort and model drag.

Ship tank electrical equipment

The power supply for the carriage motors is provided by a Ward-Leonard motor-generator set located in a separate Plant Room. This set comprises a 960hp salient pole synchronous motor and two 244 kW d.c. generators. The drive motor is arranged for automatic reactor starting, the main circuit breaker in the sub-station being controlled from the Plant Room. The generators are 0-750V machines connected in series, giving a maximum of 1,500V in the Ward-Leonard loop. The main d.c. loop circuit breaker, the a.c. and d.c. control gear, and the electronic equipment all form a composite control board in the Plant Room.

Adjacent to the main motor-generator set is a separate auxiliary motor-generator set comprising a squirrel cage motor, the synchronous motor exciter, the constant voltage exciter for the carriage drive motors and control supplies, and the variable voltage exciter for the main generators.

Current collection

Current is supplied to the carriage through conductor rails located in continuous cavities in the concrete wall on each side of the tank. Down one side run two 1,500V main d.c. conductors, of $1\frac{1}{2}$ in by $1\frac{1}{2}$ in hard drawn copper ' tee ' sections in 15 ft lengths with scarfed expansion joints at suitable intervals. A further five 1 in by 1 in tee section conductors for excitation and control are installed in the same cavity. At the other side of the tank, a set of 1 in by 1 in conductors for a four-wire 415V a.c. supply is provided, together with a separate earth conductor. All conductors are

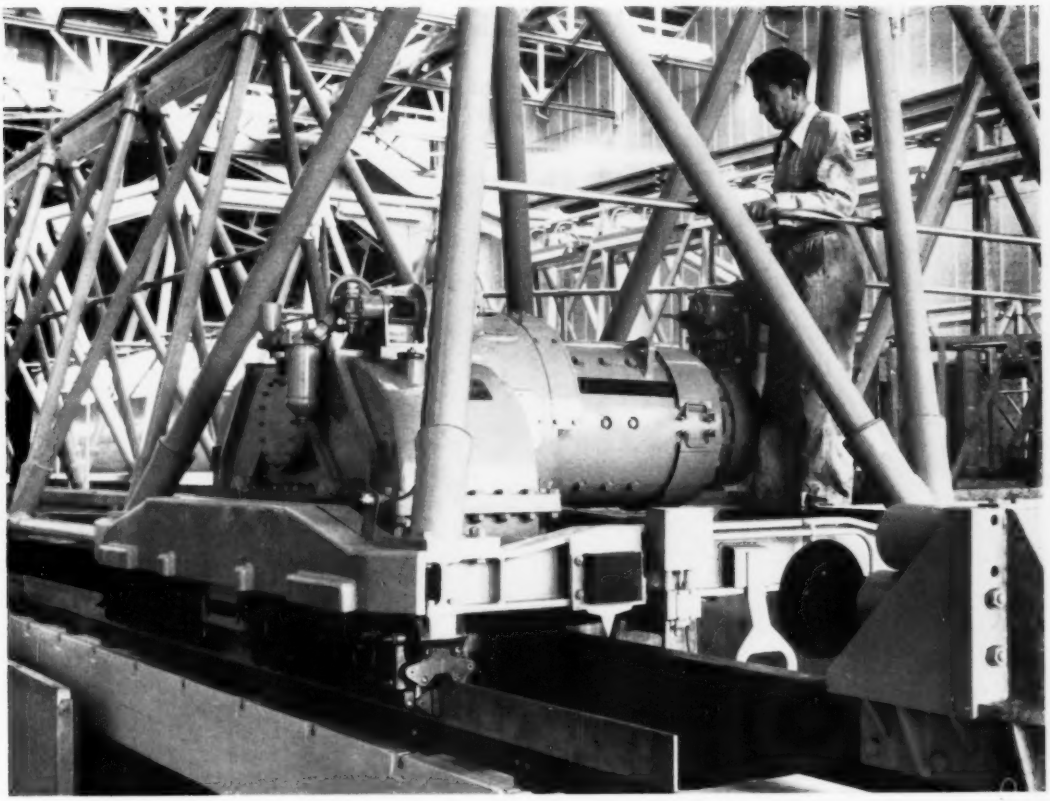


Fig. 4—One of the 300hp bogie motors on the towing carriage. The servo-operated friction brakes can be seen on the braking rail in the foreground

supported on machined insulating blocks and are accurately aligned over the whole length of the tank. Carbon insert collectors are mounted on spring loaded arms attached to a supporting frame on the carriage. From these, flexible cables connect to the motors and control gear on the carriage.

Control equipment

The control cubicles were specially designed to fit within the triangular section of the framework, and are installed in two groups, one on each side of the carriage. One group consists of an a.c. distribution cubicle for carriage services, containing flush mounting distribution units, and a d.c. rectifier cubicle providing a 7 kW constant-voltage 110V supply for motors installed in model vessels, and 6V, 12V and 24V supplies for carriage services. On the other side of the carriage is a group of two cubicles forming part of the carriage drive control system.

The bogie motors

The carriage motors themselves are drip-proof machines as used for traction service, having a combined peak rating of 1,200hp at 1,700 r.p.m., which corresponds to the top carriage speed of 50 ft/sec. They are 375V shunt wound, all connected in series. The 110V fields are connected in series-parallel across the 220V constant voltage excitation supply. Thus, due to the mechanical tie between all four motors through the wheels and rails and the same current flowing through the armatures, each motor produces the same torque. The motors are flange-mounted to the bogie gearboxes, and

at their non-driving ends the tachogenerator gearboxes are flange-mounted on the motors. These in turn carry the flange-mounted speed control tacho-generators and the tacho-generator cooling fans.

Operation of the carriage

The carriage is driven from a control desk installed at the front. All operations connected with the speed control of the carriage are undertaken from this point. Facilities are provided for automatic or manual running in either direction, and for selection of speeds and acceleration rates on automatic control, together with a direct indication of carriage speed.

An auxiliary panel is provided at the rear of the carriage to which control can be transferred when returning from the far end of the tank.

Track switches are provided to stop the carriage automatically at the end of the run. Those at the extreme ends of the tank, which operate only when inching at low speed, are of the normal lever-operated type, but because of the high speeds involved those which operate when running at speed are photo-transistor units. These are

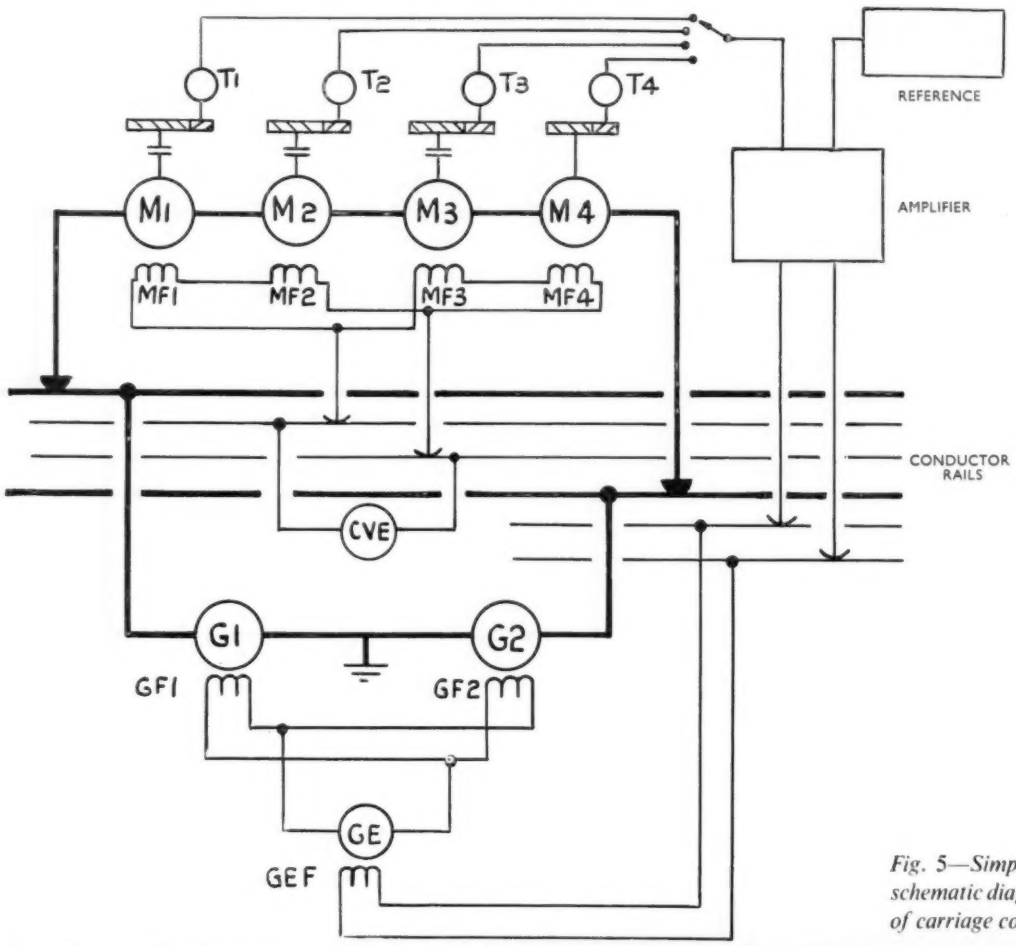


Fig. 5—Simplified schematic diagram of carriage control

T_1 --- T_4 = Tachogenerators
M_1 --- M_4 = Motors
MF_1 --- MF_4 = Motor fields
CVE = Constant voltage exciter
G_1 --- G_2 = Generators
GF1 --- GF2 = Generator fields
GE = Generator exciter
GEF = Generator exciter field

arranged to initiate the stopping sequence when the light source is interrupted by a shutter. Separate track switches are fitted for the various speed ranges, with their shutters so positioned along the tank as to obtain the maximum length of constant speed run in relation to the stopping distance needed. The appropriate limit switch is selected automatically by the speed range changing switch. To ensure the greatest possible safety factor, the photo-transistor units are duplicated, and there are monitoring facilities on the carriage control desk. They are further backed up by magnetic track switches. The latter are standard automatic train control equipments in special lightweight housings.

The electronic control system

Control is based on a voltage comparison system with error amplification (Fig. 5). Torque control is obtained through an initiating signal, obtained across the motor compole windings, which is proportional to the armature current. This influences the operation of the amplifier according to the torque limit required. This is set by a potentiometer on the control desk. Fig. 6 shows an idealised torque/distance curve for the carriage bogie motors.

The speed reference is a voltage signal set on a high resistance potentiometer. The supply to this is obtained from the 415V 50 c/s mains through an automatic voltage regulator which eliminates all normal supply variations, the output being within 1·4% of nominal. A transformer and rectifier with a smoothing circuit provide the required 1,300V d.c. reference supply. The current in the reference potentiometer is held constant by an electronic amplifier, with neon reference.

The speed signal is obtained from an a.c. inductor tacho-generator, with a voltage and frequency output proportional to speed. The optimum speed range of the tacho-generator is 750-3,000 r.p.m., i.e. 4 : 1, but the specified speed control range is over 1-50ft/sec, i.e. 50 : 1. Four tacho-generators have been provided to meet the specification, each covering a range of 4 : 1, as follows : 1-4 ft/sec, 2·5-10 ft/sec, 5-20 ft/sec, and 12·5-50 ft/sec.

Each carriage motor is arranged to drive a tacho-generator through a step-up gear unit of suitable ratio, so that for each speed range one of the tacho-generators operates over 750-3,000 r.p.m. To avoid overspeeding the tacho-generators for the three lower speed ranges, their gearboxes are driven through electromagnetic clutches, which are energised by the range selector switch as appropriate.

As a precaution against a clutch sticking and causing its tacho-generator to over-speed, a small holding brake is fitted at the tail end of the tacho-generator, which is engaged when the clutch is de-energised.

To minimize disturbances in the tacho-generator outputs, precision gears are used having minimum backlash and cyclic irregularities, together with torsionally rigid couplings.

The top range tacho-generator drive is permanently coupled, as this can never exceed 3,000 r.p.m., corresponding to 50 ft/sec, and instead of a holding brake a permanent magnet speed indicating tacho-generator is fitted.

On these inductor type tacho-generators, it has been established that small variations in output occur because of the effect on the air gap of temperature differences between the stator and rotor. To minimise these variations, these particular machines were force-ventilated by means of small blower units. The four tacho-generator d.c. excitation windings are permanently arranged in series with the reference potentiometer and included in the current control circuit. Thus, constant field current is assured and variations in field current are inherently compensated by corresponding changes in the reference current.

The tacho-generator output is stepped up by a 5 : 1 transformer, rectified, and compared with the reference voltage, and the error signal is fed into the first stage of a two-stage push-pull electronic amplifier. The output from this supplies the fields of the quick response laminated frame exciter, which in turn supplies the main generator fields. Stability of the servo loop is achieved by means of transient voltage feedback circuits taking signals from the armature voltages of the driving motors.

A current limit amplifier is included, taking its current signal from the voltage drop across the series fields of two driving motors. Its output modifies the error signal into the two-stage

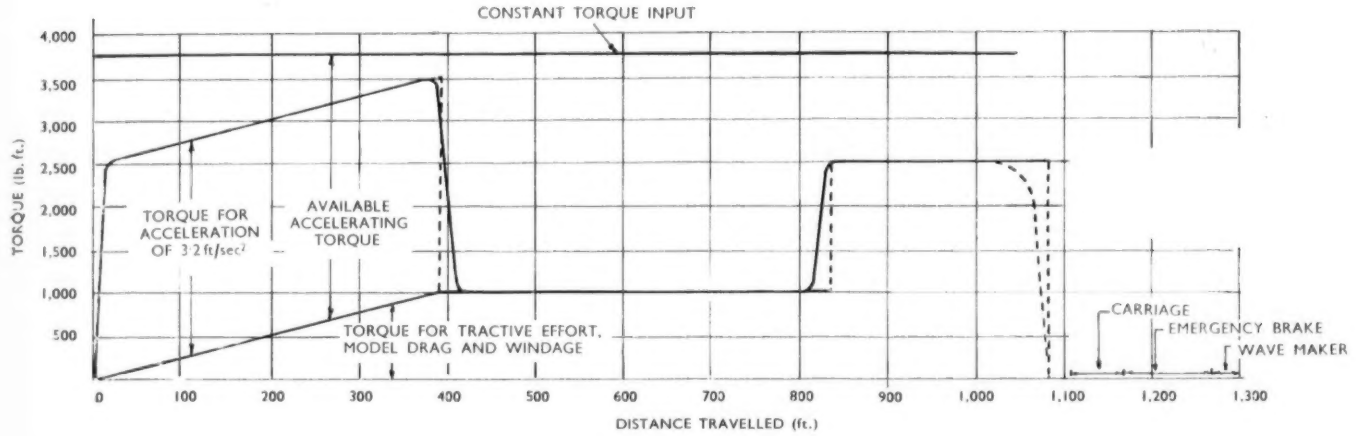


Fig. 6—An idealised torque/distance curve for the carriage bogie motors for a run at 50ft/sec. A constant speed run of 400ft is obtained, with a braking distance of approximately 250ft. This distance covers combined electrical and mechanical braking at 8ft/sec². The regenerative braking torque is 3·2ft/sec²

Fig. 7—The water tunnel circulating pump motor, a 1,062hp vertical machine. The 300hp swinging-frame dynamometer motor can be seen in the left background

amplifier. The current limit is bi-directional to operate both when accelerating and braking.

The current limit is adjustable to provide selected acceleration and braking rates.

An automatic voltage regulator is fitted to the constant voltage exciter supplying the motor fields, to counteract the effects of load variations and supply fluctuations.

THE WATER TUNNEL

The water tunnel consists of a rectangular closed circuit. The upper limb of this contains the contraction section, the working section and transition diffuser sections, and is at ground level. Two vertical limbs at 87 ft centres, and a connecting bottom limb 180 ft below the upper limb, complete the circuit and form the resorber. The resorber is of large volume, so that the water passes through it at low velocity and, under an additional static pressure head, re-absorbs the air bubbles which are released into the water stream by cavitation at the model.

The 44 in working section is of the closed jet type suitable for propellers up to 24 in dia., but an alternative working section for testing hydrofoils and similar bodies is planned. The maximum water velocity in the working section is 50 ft/sec, and this can be continuously varied down to standstill by control of the main circulating pump. In addition, the pressure and air content of the water can be varied. The circulating pump is a 92 in axial flow vertical variable pitch unit, and is the largest of its type made in the U.K. It is driven by a 1,062hp 0-147 r.p.m. d.c. motor (Fig. 7).

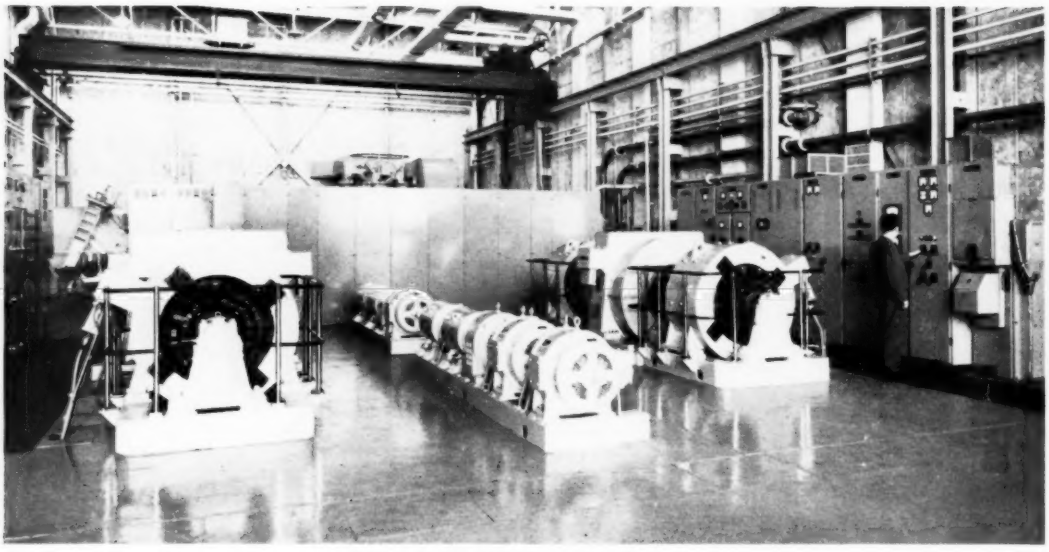


Fig. 8—The Plant Room. (Left) the water tunnel motor-generator set ; (centre) two auxiliary motor-generator sets ; (right) the carriage motor-generator set and, beyond, the control cubicles

The model under test is driven from outside the tunnel by means of a long stainless steel shaft carried in three spider bearings within the tunnel structure, downstream of the working section. The drive is provided by a 300hp swinging frame d.c. dynamometer motor. The motor is mounted on oil lift trunnion bearings which are almost frictionless. Hydraulically operated thrust and torque measuring equipment is provided.

Water tunnel electrical equipment

As with the ship tank, the power supply for the pump motor and dynamometer is provided by a Ward-Leonard motor-generator set in the Plant Room. (Fig. 8). This set comprises a 1,600hp salient-pole synchronous motor, an 0-380V 875 kW d.c. generator for the pump motor, and a 0-400V 240 kW d.c. generator for the dynamometer. Here again, the drive motor is arranged for automatic reactor starting, controlled from the Plant Room. The two main d.c. loop circuit breakers, the associated control gear and electronic speed holding equipment, all form a composite board in the Plant Room. Adjacent to the main motor-generator set is a separate auxiliary motor-generator set, comprising a squirrel-cage drive motor, the synchronous motor exciter, the constant voltage exciter for the two drives and for control supplies, and two variable voltage exciters for the main generators.

The pump motor is a vertical-spindle flange-mounted machine with ball and roller bearings, having a maximum continuous rating of 1,062hp at its top speed of 147 r.p.m. To provide adequate cooling over the speed range, a separate ventilating fan is provided, arranged to draw air in from outside the building through a dry type filter, and to expel it through the machine at high level to the outside.

A substantial fabricated steel ' A ' frame supports the motor over the tunnel corner and the pump. Jacking screws are provided in the motor flange to facilitate levelling and adjustment.

The drive to the pump is by means of a cardan shaft incorporating gear type couplings.

A shaft extension is provided on top of the motor which drives a $4\frac{1}{2}$: 1 speed-increasing precision gearbox having three output shafts. One of these drives the overspeed device, and the other two

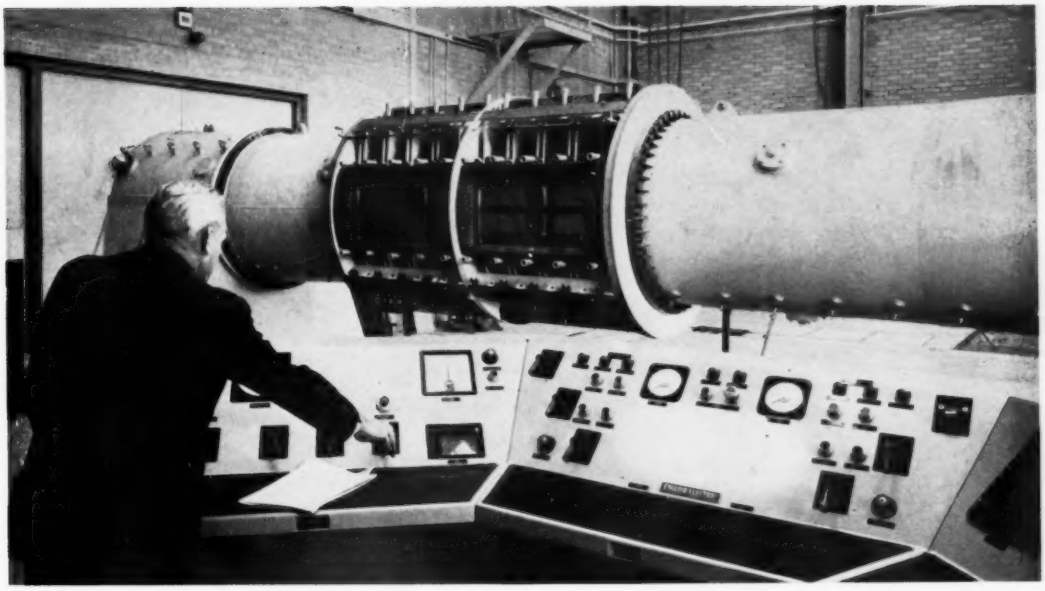


Fig. 9—The working section of the water tunnel, with the control desk in the foreground

drive speed control tacho-generators through speed-increasing gearboxes. Torsionally rigid couplings are used throughout.

The dynamometer motor is a special traction-type machine with a maximum continuous rating of 300hp with a speed range of 780-1,200 r.p.m. by armature voltage control, and 1,200-3,300 r.p.m. by field weakening. Special care was taken in balancing the armature and in balancing the frame on the trunnions, to minimise inaccuracies in torque measurement.

To provide adequate cooling, separate force ventilation is installed, and to minimise disturbances to the torque measurements due to the effect of the air flow, two diametrically opposite air outlets are provided, each with a separate extract fan mounted underneath the bedplate.

The cable connections are also designed to cause the minimum drag on the frame, to minimise errors in torque measurements. The main armature and earth connectors are in braided flexible copper, and the numerous control connections are made off in nylon cored braided flexible copper wire.

A shaft extension is provided on the tail end to drive the speed reference tacho-generator. A gear-driven cross shaft is coupled to an overspeed device and an indicating tacho-generator.

The pump motor and dynamometer are controlled from a console desk installed adjacent to the working section of the tunnel (Fig. 9). Hand and automatic control of speed of the two machines is provided with hand control in reverse. Control of the weighing mechanisms for torque and thrust measured on the dynamometer, and measurement of hydraulic conditions within the tunnel is also provided on the desk.

The speed control systems are similar to that for the carriage. In the case of the pump motor, the specification requires the speed to be held constant within plus or minus 0·1% of any specified speed within the range of 14·7 to 147 r.p.m. with a repeatability of plus or minus 0·25% of the set speed.

To cover this range, two tacho-generators have been used, each covering a 4 : 1 range, as follows, 14·7-56·8 r.p.m. and 39 to 147 r.p.m.

Each tacho-generator is driven through a speed increasing precision gearbox, of suitable ratio so

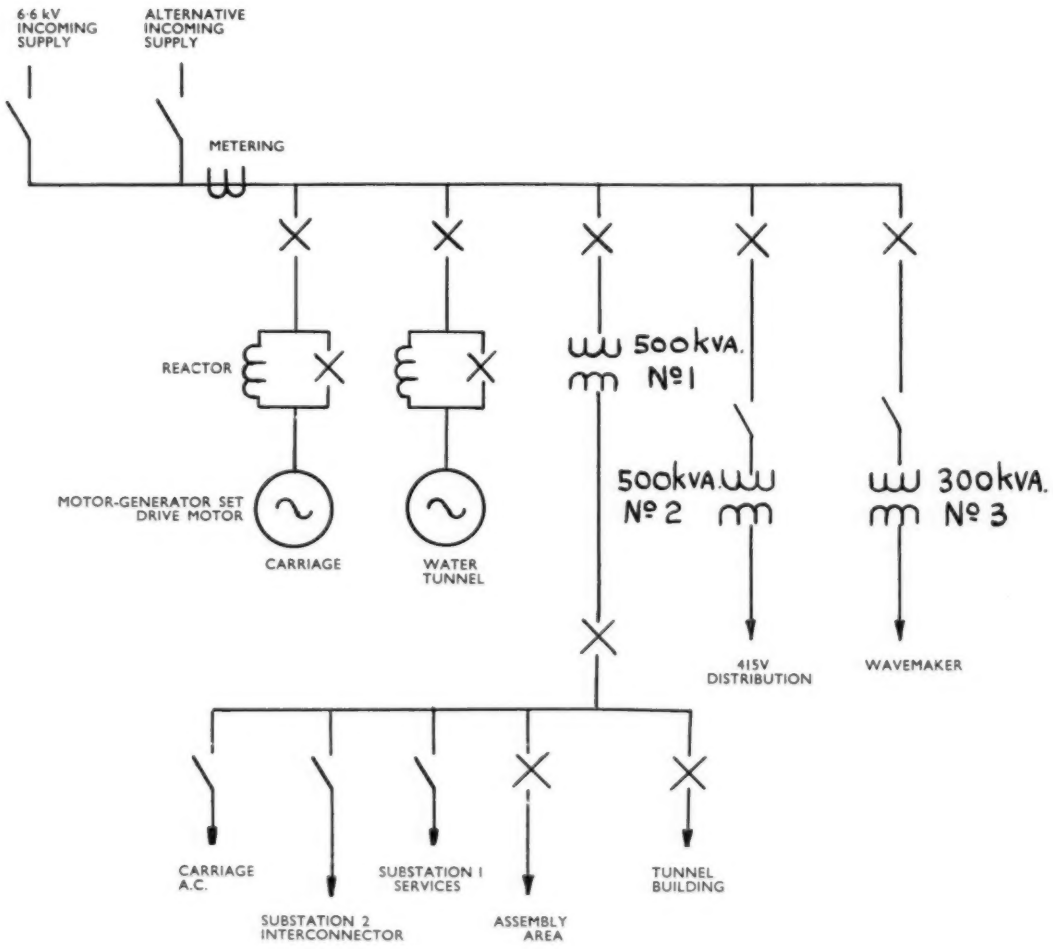


Fig. 10—The a.c. distribution diagram

that they operate over their optimum range of 750-3,000 r.p.m.

As with the carriage drive, the tacho-generator for the lower speed range is driven through an electro magnetic clutch, energised by the range selector switch.

The tacho-generator for the upper speed range is solidly coupled, and is fitted with a speed indicating tacho generator at the tail end.

The performance specification of the dynamometer requires the speed to be held constant within plus or minus 0·1% of any specified speed within the range of 780-3,300 r.p.m. with a repeatability of plus or minus 0·25% of the set speed. As this is a speed range of approximately 4 : 1, one tacho-generator only is necessary, and this is driven directly from the dynamometer shaft without intermediate gearing.

A motor-operated rheostat is arranged to weaken the field automatically when the armature voltage range has been completed.

On both the pump motor and dynamometer, regenerative braking is provided to bring the drives to rest in emergency stopping conditions.

SWITCHGEAR AND TRANSFORMERS

The main 6·6 kV switchgear is an eight-panel 150 MVA oil circuit breaker switchboard, comprising two hand-operated isolators for incoming supplies ; an incoming metering panel ; two solenoid operated circuit breakers supplying the motors driving the ship tank carriage and water tunnel Ward-Leonard sets ; and three hand-operated circuit breakers supplying distribution transformers (Fig. 11). The distribution system is shown in Fig. 10.

The three transformers are 6·6 kV/415V O.N. indoor ground mounting units, two of 500 kVA and one of 300 kVA. Two are installed remote from the main substation and are fitted with interlocking h.v. off-load isolators.

The main l.v. switchgear is a combined unit comprising an 800 A incoming and two 400 A outgoing air circuit breakers, and one 60 A and two 300 A fuse switches. The outgoing air circuit breakers supply in turn a number of distribution fuse switchboards for l.v. services throughout the establishment.

ACKNOWLEDGMENTS

The author thanks the Ministry of Works for permission to publish this article.

Fig. 11—The eight-panel 6·6kV 150MVA switchboard

Distribution of Electricity on Board Ship

by M. J. BOLTON, A.C.T.(L'pool), A.M.I.E.E., A.I.Mar.E., Technical Assistant to the Superintendent Engineer, Cunard Steam Ship Company, (formerly of Fusegear Division, The English Electric Company)

IT HAS BEEN RECOGNISED in marine engineering circles generally that, for certain types of ship, advantage is to be gained by installing auxiliary electrical systems employing alternating current in preference to direct current. Ashore, a.c. has been used almost universally for over thirty years and there have been improvements in distribution technique and the development of apparatus. This article deals generally with the factors influencing the use of a.c. in marine auxiliary systems and with the application of experience gained in industry upon certain types of protective equipment, notably H.R.C. fuses.

Historical background

The 220V d.c. two-wire system is still extensively used in some ships, particularly dry cargo liners, distribution being effected through open type panel-mounted circuit-breakers and knife-switches. Equipment of this type has disappeared almost entirely from the industrial scene, but it has been retained in ships, because the pace of marine electrical development has been slow. There are several reasons for this. One reason is that until the last decade most ships were propelled by steam turbines and earlier by steam reciprocating engines. Boilers were essential and, logically, steam was used for the auxiliaries also. Steam machinery was simple and reliable and there was very little incentive to the marine engineer to look for other means of providing auxiliary power. His generating plant was, therefore, small. The scene has now changed, the average new merchant vessel is propelled by a diesel engine or engines and, if steam machinery were to be used, a special boiler would be necessary. The alternative of electric power in these ships is very attractive ; it is available at short notice and advantage can be taken of greater working efficiency. A limited amount of steam is used in most motor ships for such purposes as heating accommodation, and this is often supplied by a composite exhaust-gas/oil-fired boiler.

Another reason for this conservatism is that most ships are expected to operate in any part of the world and they must do so safely and efficiently. Factors of safety must necessarily be higher than those ashore, since failure of one unit may place a ship in danger. Equipment must be simple and capable of running trouble-free for long periods throughout the life of the ship, which may exceed twenty-five years. Account must be taken of the movement of the ship and of the effects of vibration, and particular care is needed to prevent deterioration of insulation and corrosion of components in humid salty atmospheres. Electrical equipment is more vulnerable to these conditions than is most engine-operated plant, and the additional expense involved in carrying electrical staff for maintenance has to be carefully considered.

Thirdly, marine electrics tend to receive rather less attention than they deserve, and resistance to new developments is occasionally encountered. This is to be expected, since few shipping concerns—with the exception of the larger oil tanker and passenger line companies—employ electrical engineers, either in the design office or in the ships themselves. Few marine engineers have time to keep up with new developments in electrical engineering and generally they defer acceptance of any new electrical equipment until it has been thoroughly proved in service.

As one would expect, the use of electricity in ships has developed in much the same way as it has ashore. Up to 1918, 60V d.c. was generally accepted and as the number of electrical services

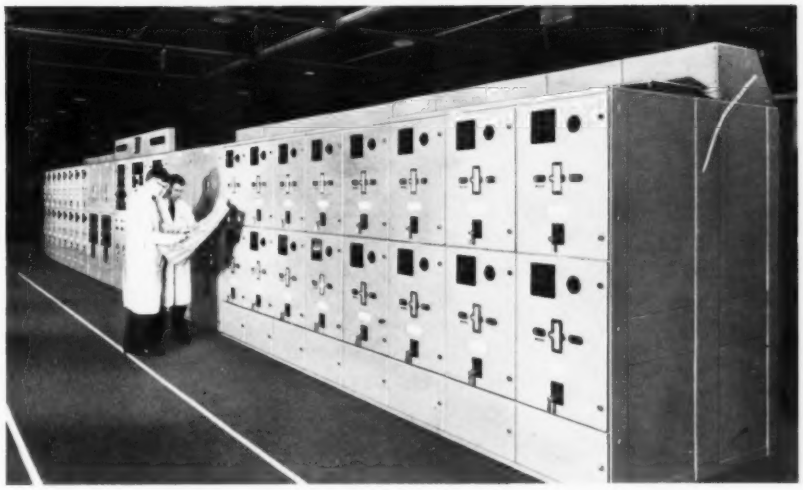


Fig. 1—An 'English Electric' 440V a.c. main switchboard for a large passenger liner

increased, so the voltage rose to 110V d.c. and 220V d.c. For auxiliaries the d.c. voltage has remained at 220V up to the present day, and it is not expected to increase in the future.

Marine alternating-current systems were known as early as 1920 when a.c. was applied to a fleet of tankers, but it was not until World War II that it came into wide use in this class of ship. Since the war, many dry cargo and passenger ships have been built with a.c. installations, particularly in Europe and the U.S.A., and the numbers so equipped are steadily increasing. There has not been the same wholesale changeover as in tankers, because with some types of ship the advantages of a.c. have been marginal.

The present situation

It will be seen that the degree of marine electrical development to date has depended very much upon ship size and class. These are discussed below.

The passenger liner

It is only during the last five years that the 440V, three-phase, distribution system has established itself as the most popular for large passenger ships. The recent building of ships having plant capable of generating up to 7MW of power at 220V d.c. shows that the change has been long overdue. Fig. 1 illustrates modern trends in the design of large main switchboards.

The tanker

Without exception, all tankers now being built for the principal tanker companies have 400/440V, three-phase, three-wire unearthed neutral systems, and there is little doubt that this will continue as a standard for many years to come. This may seem inadequate in the light of the fact that tankers of over 100,000 tons d.w. have been built and that tonnages may increase still further. But it must be realised that these ships are composed mainly of oil tanks and the electrical power requirements of a '100,000 tonner' are not so very much greater than those of a 32,000 tonner, especially when it is realised that as the size of ship increases, more of the auxiliaries are engine-driven. The maximum sea-load may only amount to 1MW.

Tankers were the first ships to adopt a.c., because their requirements are straightforward, there being no need for variable speed electric drives for deck machinery.

The cargo liner

Until recently, British cargo ships have used d.c. at voltages up to 220V almost exclusively, and the supporters of this sytem still outnumber those favouring a.c. This is not the case in Europe,

where more than three-quarters of the cargo ship-owners standardise upon a.c., or in the U.S.A. where almost all new ships use a.c.

Miscellaneous

Under this heading may be classed trawlers, ferryboats, tugs and special purpose craft of all sorts. Most of them are relatively small and will probably continue to use d.c. at 110V and 220V as long as it remains economic to do so.

This general pattern gives sufficient indication that in due course a.c. installations will be used in almost every type of ship. How soon this will happen depends upon the rate of development and acceptance of a.c. deck machinery.

Factors affecting the choice

In considering the choice between a.c. and d.c. for the auxiliaries of a particular ship, several factors require consideration. These are here reviewed.

Normal load currents

It is generally accepted that the voltage for a d.c. auxiliary installation should not exceed 250V. This is due partly to considerations of electrical safety and perhaps to anticipated commutator troubles at higher voltages. The voltage being fixed, therefore, the current generated varies in direct proportion to the electrical load. For small ships, the currents are likewise small, but as the ship approaches the size of a modern cargo liner, the currents generated can be quite heavy, necessitating heavy conductors in machines, cables and control equipment. A considerable saving in overall weight and space required can be made by changing over to the three-wire, 440V system. In large passenger vessels, the 440V a.c. system has been accepted by most shipowners and to reduce currents still further, 3·3kV, three-phase systems are now under active consideration for generation and primary distribution.

Short-circuit currents

As the normal load currents rise in proportion to the size of the electrical installation, so do the short-circuit currents, and in large ships this is the most serious electrical problem. Reduction of these currents in d.c. ships can be made by dividing the system, but the only really satisfactory solution is to raise the distribution voltage, and to do this it is necessary to use a.c.

Variable-speed drives

There is no argument that where variable-speed drives are necessary, direct current is easier to apply than alternating current. It must be admitted, however, that when d.c. only was available, the variable speed facility was often included because it was easy and cheap to do so, and not because it was really necessary. It has been found that for many of the drives which have had variable speed in the past, this facility is not required at all, and a.c. single-speed squirrel-cage motors are adequate. Even induced-draught and forced-draught boiler fans, for which variable speed used to be considered essential, are now driven by single-speed squirrel-cage motors in many instances.

For most ships, almost all engine-room auxiliaries can be driven by simple squirrel-cage motors. It is for deck auxiliaries that speed variation is so often considered essential, although successful winches with single-speed squirrel-cage motors have been developed.

Variable-speed a.c. deck machinery falls generally into three categories which are about equal in popularity. These are Ward-Leonard combinations; two- and three-speed squirrel-cage motors ; and hydraulic machinery operated from squirrel-cage motors.

Commutators

Approaching the choice from first principles, it is an anomaly of the d.c. system that the generators produce alternating current and, by means of the commutator, rectify it before it leaves the machine terminals. Motors then receive the direct current, but to function they must convert it into alternating current, again using the commutator. The absence of commutators in the a.c. system leads to considerable saving in capital costs, maintenance costs, space and weight.

Motor-starting currents

D.C. motors cannot normally be started direct-on-line ; severe damage could occur if this were

attempted. The starting current is usually limited to something less than twice normal load current by starting resistances inserted in series with the armature. The robust a.c. squirrel-cage motor, on the other hand, is started direct-on-line wherever possible and up to eight times normal load current can result during the starting period. This simplifies the motor starting and control equipment, but when several motors which together form a substantial part of the load are started at once, the resulting voltage dips can affect other services such as lighting. Careful specification of the generator reactances can reduce these dips to a minimum and quite rapid recovery can be obtained using the latest type of automatic voltage regulator.

Cost

While for the average British dry-cargo ship the initial overall cost is at present about the same for both a.c. and d.c. installations, there is no doubt that as more a.c. ships are built their cost will fall. This has already happened in the U.S.A. and in Europe.

The number of a.c. passenger ships in service is small, but there is sufficient indication that a.c. is more economic than d.c.

From the hundreds of a.c. tankers now in service, there is no lack of evidence that installation and running costs are much lower than they were with d.c. systems.

Development

Because of the almost universal adoption of a.c. ashore, the rate of development of a.c. equipment has been rapid. Most of this development work, which is naturally continuing, can be used to advantage in ships. An important example of this is the emergence of the 'on-load' fuse-switch which can be used successfully to control most of the feeder circuits in a main or subsidiary switchboard, thus achieving substantial savings in cost, space and weight.

Other considerations

Much more standard equipment is available for the galley, laundry and hotel services if a.c. is used. Advantage may also be taken of the reliable and economical a.c. fluorescent lamp.

Transformers, which are static pieces of apparatus requiring negligible maintenance, can be used to supply power at different voltages according to requirements. They also serve to divide the system into sections, so that an earth fault in one section cannot combine with an earth fault in another.

Electrical systems in ports visited are almost invariably a.c. and an electrical supply from shore to ship can be achieved quite simply. Account must be taken of any difference in operating frequency and voltage.

Comparison of a.c. electrical systems ashore and afloat

In industry in the U.K. electrical power is obtained from the National Grid and the frequency, voltage and system type are, in general, standardised. A ship generates her own power and a wide choice of systems is available. On d.c., the voltage can be 110V, 220V or 250V, and the system a single-wire with hull return or two-wire with both conductors insulated. On a.c., single-phase or three-phase, three or four-wire may be selected with voltages up to 440V, 50c/s or 60c/s. Hull return systems have been little used since the 1930's, and the modern d.c. ship will have a 220V two-wire unearthed system. In an equivalent a.c. ship 440V, three-phase, three-wire with insulated neutral will be preferred. The three-phase, four-wire neutral earthed system so common ashore is not generally favoured, in spite of its basic advantages, which are (i) the voltage to earth is limited to $\frac{1}{\sqrt{3}}$ of the line voltage, i.e. 254V in a 440V system ; and (ii) when a fault occurs the circuit is automatically isolated by the protective gear.

Desirable as these features may appear in most installations there are several reasons why the earthed neutral system is not normally suitable for ships. These are enumerated below.

(i) Automatic tripping of a circuit in which the insulation between one phase and earth has failed can be a source of danger to the ship if the circuit is an essential one. This cannot occur if the system is unearthed, because there is no return path to the

neutral for the fault current. The fault can persist for some time without causing damage until such time as an engineer can change over to a standby auxiliary and investigate the trouble. He will know that a fault is present from the earth leakage indication equipment. It is, of course, necessary with an insulated system to clear an earth fault as quickly as possible, so that a similar fault on another phase will not combine with it to form a short-circuit across the phases.

(ii) The risk of fire exists if heavy fault currents are permitted to circulate through the steelwork of the ship. Excepting the unusual case of simultaneous earth faults on different phases, they cannot do this if the neutral is unearthed. This is of prime importance in tankers, and Classification Societies insist that electrical systems in such ships shall be unearthed.

(iii) An earthed system, especially if resistance-earthed, requires the use of earth-leakage protection relays. The use of relays in ships is to be discouraged where possible in the interests of simplicity and ease of maintenance.

The electrical system on board ship is different from that in industry in that much greater emphasis must be placed upon simplicity, reliability and safety. Failure of electrical plant in a factory is sometimes serious, but it is rarely dangerous. If the industrial electrical engineer has difficulty in repairing his plant, he can call in a specialist to bring the required spares and to assist with the work. On board ship, the engineer is on his own, possibly thousands of miles from the nearest port, and he must be able to carry out effective repairs quickly. It is very important that he should be given simple, reliable and safe equipment to enable him to do this.

From the rapid increase in the size of ship's generating plant a situation has arisen which is not entirely in keeping with the conservative nature of marine engineering generally. Fig. 2, which is derived from British Standard Specification fault-current ratings, shows how, for a.c. circuit-breakers operating at all voltages, the recommended maximum r.m.s. symmetrical short-circuit current is about 44kA ; yet for new ships, increasingly higher breaking capacities up to 75kA at 440V continue to be specified. The primary cause of this is the increase in the size and number of generators connected in parallel without a proportionate increase in operating voltage. In a.c. ships, because the generators are so close to the main switchgear, a high degree of asymmetry appears in the fault current wave, thereby further increasing fault severity. Because of these unusual circumstances, which affect particularly the circuit-breakers, much thought has had to be given to system design and special proving tests for the equipment have been necessary.

Selection of generators

In selecting generators the electrical loading is estimated in much the same way as it is on shore. In a passenger vessel, due account is taken of the diversity factor of the hotel services and the normal sea-load is roughly calculated. To this basic load is added a percentage to allow for future additions of electrical equipment over the life of the ship, and the resulting figure is then divided into convenient units, usually three or four, and a further unit is then added to serve as a standby so that maintenance work may be carried out on the sets in rotation. For emergency use there is an emergency diesel generator, mounted high in the superstructure, so that it will be available for emergency use if the engine room should become flooded.

The division of generators in a cargo liner is broadly similar, except that the harbour load must also be taken into account. The power taken by cargo-working machinery may exceed the sea-load. In the modern diesel-driven cargo liner, the generating sets are driven by diesel engines also and it is normally unnecessary to provide a separate emergency generator.

The generating capacity of tankers almost always consists of two turbo-, or diesel-, alternator sets of some 400kW to 800kW each, depending upon the size of the ship. Each machine must be able to carry the whole sea-load, so that except for navigation in restricted waters, one generator only will be running. For emergency services it is usual to have a diesel-alternator set of some 150kW to 200kW.

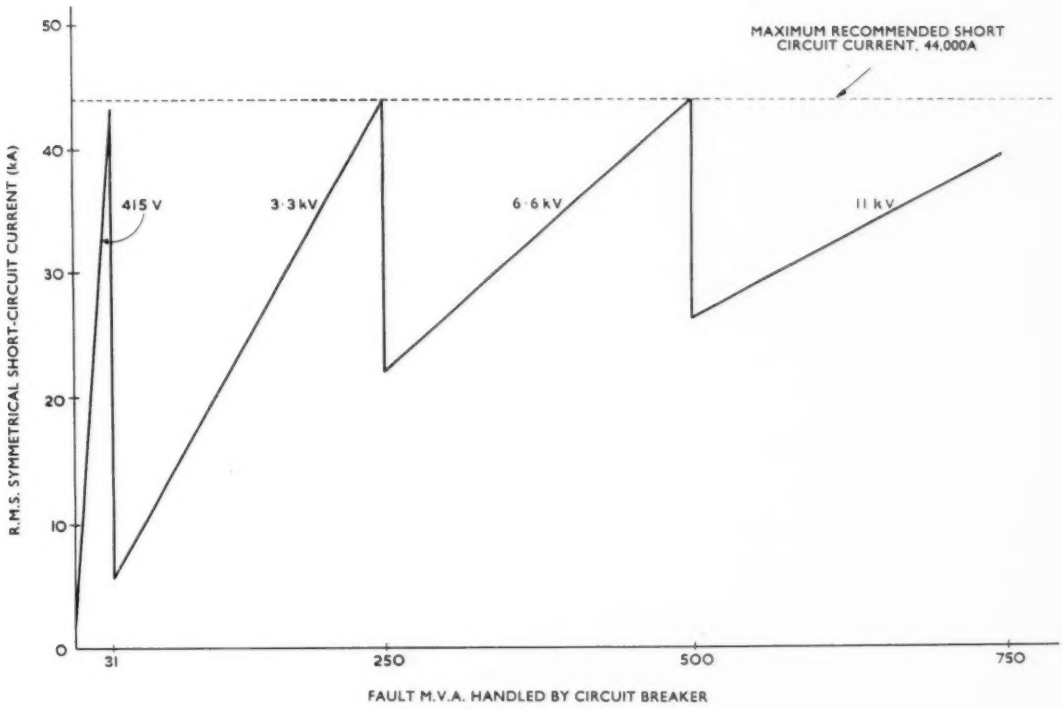


Fig. 2—Maximum recommended short-circuit currents for a.c. circuit-breakers

Protection and control of generators

In a ship it is vital that the supply of electricity be maintained for engine-room auxiliaries and for such services as steering and navigation. Several circumstances which may arise must be catered for to maintain continuity of supply.

Overcurrents resulting from overloading of the system

Overload conditions may occur when too few generators are in circuit to carry the load on the system. A plain overcurrent release on the circuit-breaker controlling the alternator is not suitable for this condition, because tripping of one generator would lead to progressive overloading of the others, until electricity supply is lost completely. The only remedy is to shed some of the non-essential loads until more generating capacity can be made available. This is done by a preference tripping relay which monitors the output from the alternator. There may be one or two preference tripping stages, which will operate in succession if the overload persists. Additional overload relays with long time settings may be included also as back-up protection if the preference tripping devices should fail, or prove ineffective in certain instances.

Overcurrents resulting from short-circuit faults

Fault overcurrents can be initiated in three zones as shown in Fig. 3 :—

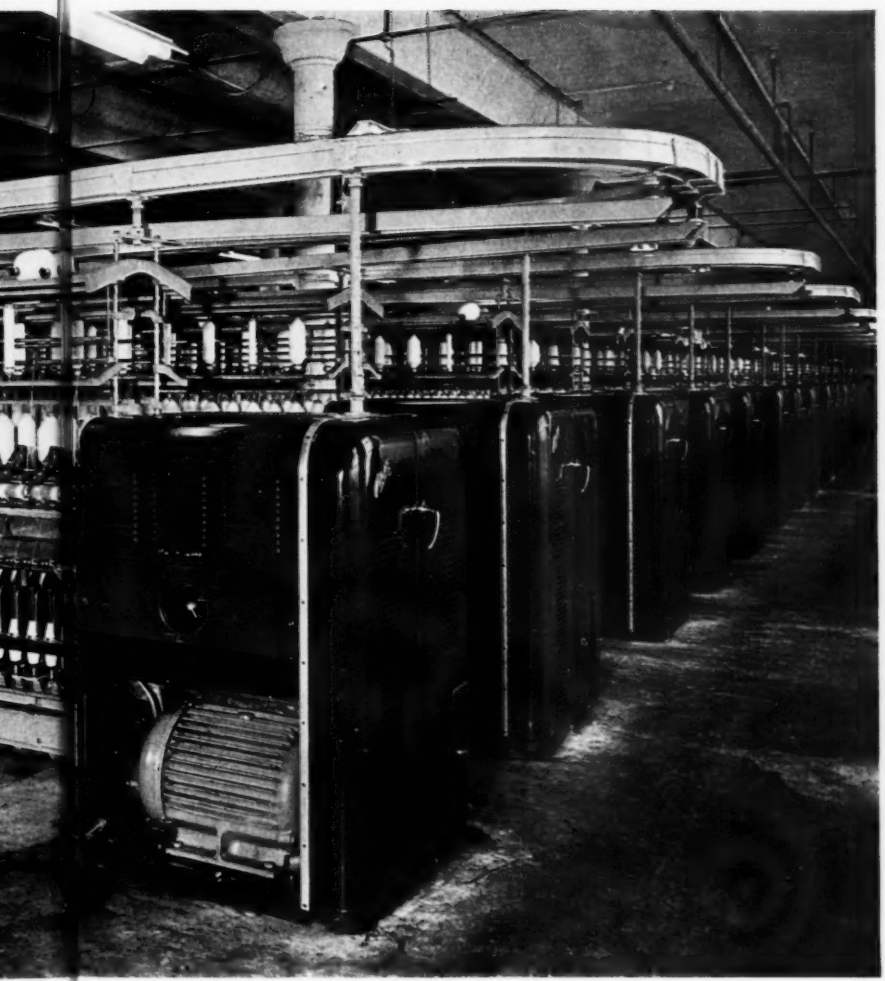
Zone 1—From feeder circuit-breakers or fuse-switches outwards.

Zone 2—Between alternator circuit-breakers and feeder circuit-breakers or fuse-switches, i.e. the busbar chamber and connecting risers.

Zone 3—From the alternator circuit-breaker up to and including the alternator.

Fault currents in Zone 1 should be detected and interrupted by feeder circuit-breakers or H.R.C.

A view down the line of sixty-four new ring-spinning
Company, Preston, Lancashire. These frames, supplie
' English Electric ' 16 hp totally-enclosed fan-cooled squ
In the recent conversion of this mill from steam to e
switchgear and fuse



nning nes in the No. 1 Ring Room of the Tulketh Spinning supplied by Platt Bros. (Sales) Limited, Oldham, are fitted with led squirrel-cage motors with smooth acceleration characteristics. n to electric drive a considerable amount of 'English Electric' nd fuse gear was also installed.

fuses. In the unlikely event of failure of one of these, high-set overcurrent protection must operate to trip each of the generator circuit-breakers.

Every precaution is normally taken to ensure that Zone 2, which is the most vital zone in the electrical system, is not exposed to risk of a short-circuit fault. Nevertheless, main busbar faults have occurred in ships in the past and the possibility that they will occur again cannot be ruled out ; protection must, therefore, be provided. Short-circuit protection for Zone 2 and back-up short-circuit protection for Zone 1 may be provided by time-delayed overcurrent relays, which detect the short-circuit current, or by time-delayed under-voltage relays which detect the substantial drop in voltage which occurs under short-circuit conditions.

Fault overcurrents arising in Zone 3 from inter-phase faults in the alternator windings, or in the cable between the circuit-breaker and the alternator, cannot be detected by devices in the circuit-breaker alone, since the fault current will not flow through the circuit-breaker. The most common way of dealing with this situation is to instal some form of 'circulating-current protection'.

Failure of prime-mover

Failure of the prime-mover to deliver power will result in the alternator being driven as a motor with the prime-mover as a load. This will almost certainly overload the remaining alternators and may result in damage to the prime-mover. A time-delayed wattmetric type reverse-power relay is necessary to trip the alternator circuit-breaker.

Field failure

Field failure protection can be provided quite simply by installing an undercurrent relay in the exciter circuit. It is not regarded as essential in all cases, but when it is used its purpose is to trip the circuit-breaker so that the alternator does not absorb heavy magnetising current from the re-maining alternators connected to the system.

The most usual forms of alternator protection have been given above, but additional protection may be provided for such conditions as overspeed, over-voltage, phase un-balance or failure of prime-mover auxiliaries, depending upon the size and type of machines employed.

Protection of feeders

All feeder circuits comprise the cable carrying the supply current and the apparatus receiving the supply, whether it is a simple lamp, a motor or a switchboard.

If the apparatus is a simple lamp or group of lamps it cannot be given overload protection, because upon a fixed voltage system lamps cannot be overloaded. Protection is only required to safeguard the cable against fault currents. If a motor is considered, overload protection for the machine is invariably provided within the starter. Again, therefore, protection is only required for the connecting cable against fault currents. The case of a subsidiary switchboard or distribution board is similar. The sub-circuits are individually protected and it is only the connecting cable and the busbars of the switchboard or distribution board which require fault-current protection.

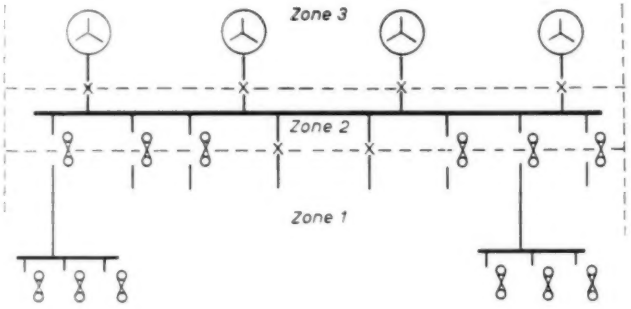


Fig. 3—An example of distribution system layout, showing zones of protection

For many years H.R.C. (high rupturing capacity) fuses have fulfilled these protective functions most effectively and they have justified themselves by experience. During this time technical evidence

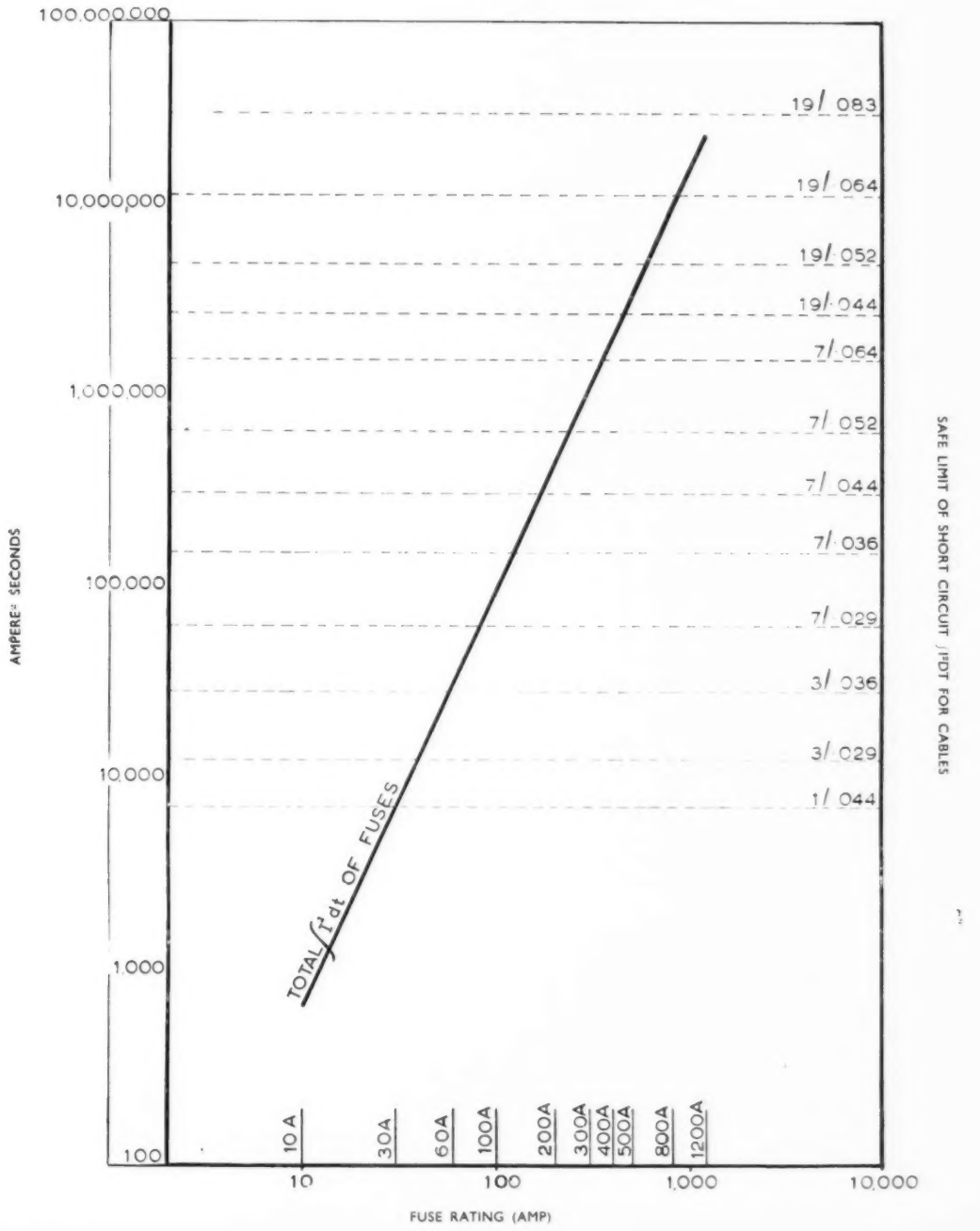


Fig. 4—Thermal protection of cables under short-circuit conditions

has been built up to verify what is now accepted fusegear practice and to broaden its scope.

The feeder cable

Under fault conditions damage to cables may be thermal or electro-magnetic or both. Tests have been performed by cable makers to set limits to the amount of through-fault energy that a cable will withstand without damage. Fig. 4 is a typical curve giving no-damage limits for through-fault energy for a range of cables.

It will often be found, particularly with the smaller cable sizes, that a feeder cable will not withstand the calculated prospective fault current. With many forms of protection, the asymmetrical fault current peak has passed before interruption takes place after perhaps several cycles and it is this current peak which causes the greatest electromagnetic stress between conductors. Obviously, since the stress varies in proportion to the square of the current, it is of great advantage to use a protective device which operates before the current peak is reached. The heat generated under fault conditions varies not only with the square of the current, but also with the time for which the current is flowing, and again it is essential to cut the current off as early as possible to prevent damage to the cable insulation. 'English Electric' type 'T' cartridge fuse-links operate sufficiently early to give both thermal and electromagnetic protection; incorporated in Fig. 4 is a curve showing the maximum energy let-through figures for a range of fuses. From curves of this type it will be found that H.R.C. fuses selected in accordance with the normal current rating of the cable or to suit the starting current of a motor will give adequate protection against fault damage. The data used in drawing the curves is obtained from thermal tests only, because although the electromagnetic considerations are equally important, it has been found that if a cable will withstand the thermal stress associated with a given amount of energy, it will be satisfactory mechanically also.

Whilst the primary duty of H.R.C. fuses is the protection of circuits against short-circuit faults, they can give a high degree of overload protection if they are chosen to suit the thermal characteristics of the apparatus protected. This is particularly applicable to cables, and experience in industry has proved that H.R.C. fuses can be chosen to give adequate short-circuit and overload protection to cables.

A significant economy in cable costs accompanies the use of H.R.C. fuses. It is never necessary, as it is with other forms of protection, to increase the rating of the cable above normal to allow for the effect of fault currents.

The location of the fault

It is possible when specifying protective gear for feeder circuits to be influenced wholly by normal circuit requirements and by the desired breaking capacity, and to accept that the protection is satisfactory if, under short-circuit conditions, the fault is cleared. It is all too often taken as inevitable that severe damage will occasionally result at the location of a fault before the current is interrupted. In ships, where fault levels are rising so rapidly, and where the risks attendant upon accidental fire or damage are greater than they are ashore, full use can be made of the energy-limiting properties of H.R.C. fuses.

The 'cut-off' feature of H.R.C. fuses is most marked at high short-circuit current levels, but even at very low prospective currents, such as are encountered in lighting circuits, there can be a considerable reduction in damage and fire risk.

Discrimination between H.R.C. fuses

Discrimination between H.R.C. fuses protecting distribution circuits is necessary to ensure that, under fault conditions, the only fuse to operate is the one protecting the faulty circuit. To obtain discrimination between 'English Electric' H.R.C. fuses, under all fault conditions, it has for many years been the practice to make the larger or major fuse at least twice the current rating of the smaller or minor fuse. This empirical rule has covered the requirements of every type of circuit encountered normally, but occasionally closer discrimination is needed. In such cases, using the I^2t values allocated to the fuses, it is possible to check accurately whether, in fact, discrimination can be obtained. The way in which this can be done was described in a recent paper* presented to The Institution of Electrical Engineers.

* *Paper No. 2805U, January 1959, by E. Jacks.*

H.R.C. fuses as back-up protection

The practice of backing up a circuit-breaker with H.R.C. fuses is often regarded as a half measure reserved for the rejuvenation of old equipment no longer equal to the duty demanded of it. This is still true, but in some large modern ships it is also becoming accepted as the only solution to a particular problem. The problem is that prospective fault currents have risen so high that, irrespective of the circuit normal current ratings, main switchboard feeder circuit-breakers need to be of a large minimum size, perhaps as high as 1600A, so that the size and weight of the switchboard are grossly inflated together with the cost. Back-up H.R.C. fuses cut off the asymmetrical fault current peak and it is then possible to revert to the appropriate circuit-breaker sizes.

The use of circuit-breaker back-up fuses is not restricted to a.c. circuits only. An interesting case occurred recently in connection with some large d.c. circuit-breakers required for a passenger liner. It was thought prudent, in view of the extremely high prospective short-circuit currents, to back-up circuit-breakers up to 2,700A rating with fuses having a tested rupturing capacity of more than 200kA peak.

Because protective gear is usually successful in interrupting short-circuit faults, it follows that few people have a full appreciation of the potential for danger and destruction inherent in the electrical system of a large passenger liner. At the Company's laboratories at Stafford it was possible recently to stage, for the benefit of a party of senior marine electrical engineers, a full-scale demonstration of the efficiency of H.R.C. fuses. The equipment under test was a 150hp triple-pole motor starting contactor, backed-up by three 450A 'English Electric' type T cartridge fuses. Three tests, as follows, were performed at a line voltage of 415V and a prospective r.m.s. symmetrical current of over 66kA (i.e. 50MVA at 415V).

(*i*) *Through-fault current with contactor closed*—As the fuses operated, a slight flash occurred on one pole of the contactor.

(*ii*) *Making test : with fuses*—With new fuse-links fitted the contactor was closed on to the fault. Slight arcing occurred at the contacts of the contactor, but it was fit for further service.

(*iii*) *Making test : without fuses*—With solid copper links fitted in place of the fuses, the contactor was again closed on to the fault. In the violent explosion which took place, flames and smoke were emitted and hot metal was flung for a radius of fifty yards. The contactor was damaged beyond repair, all contacts having burned away.

The tests demonstrated conclusively the necessity of paying the closest attention to short-circuit protection. The test conditions were actually less severe than those which have been calculated for some large modern ships.

Standard specifications for H.R.C. fuses

The rise in short-circuit currents in marine electrical installations has outstripped all existing standards for fuses in this country. B.S.88, which is the most widely recognised standard specification for fuses, was last revised in 1952 and it is now well out of date for both land and marine work. It has maximum categories of duty of 33,000A for d.c. and 46,000A r.m.s. symmetrical for a.c., whereas calculated short-circuit currents for some ships now exceed 100,000A for d.c. and 75,000A for a.c. It is of interest that, in anticipation of a growing need, 'English Electric' already have a complete range of fully tested fuses available to cope with the highest fault level likely to be met in a ship.

Control of feeders

It has been established that the H.R.C. fuse provides the most suitable form of protection for feeder circuits and it is equally suitable for all sizes of circuit. Unlike circuit-breakers, the interrupting element is not used also for circuit control, and a separate switch is necessary. Because the H.R.C. fuse limits the flow of fault current, both through the circuit protected and the switch, the physical size of the switch bears a direct relationship to its normal current rating, and for 'English Electric' Superform fuse-switches this is unchanged for all fault currents obtainable in practice.

Fuse-switches must be capable of three duties : (i) making and breaking normal full-load current ; (ii) making on to a short-circuit fault ; and (iii) making and breaking stalled-rotor current in the case of motor circuits.

The reason for requirement (iii) is not always immediately apparent. Under normal conditions,

it is the duty of the motor-starter contactor to make and break starting and load currents, whilst the controlling fuse-switch acts as an isolator. It does happen, however, sometimes under stalled-rotor conditions, that a contactor does not open correctly, due either to a failure in the control circuit or to welding-in of the main contacts. Under these conditions it is acknowledged to be dangerous to open the circuit with an 'off-load' isolator. Several cases of serious accident from this cause have been recorded.

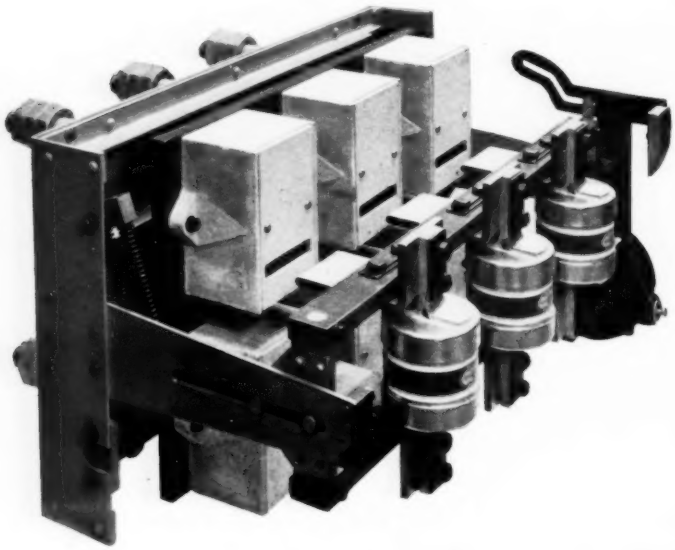


Fig. 5—A 750A 'English Electric' Superform triple-pole fuse-switch

For lighting and similar low current circuits, tumbler switches of the required size are readily available, although in some ships the lighting need not necessarily be switched at all, but may be left permanently on. Isolation of a circuit may then be achieved by removal of fuse-carriers. Whether lighting circuits are switched or not, it must be recognised that occasionally fuses will be closed accidentally on to a short-circuit fault. The degree of safety with which this may be done depends to some extent upon the operator, but provided it is inserted cleanly, a well designed fuse-fitting will be suitable for this duty.

For straight switching of all other types of feeder, 'on-load' fuse-switches are readily available up to 750A and there is no

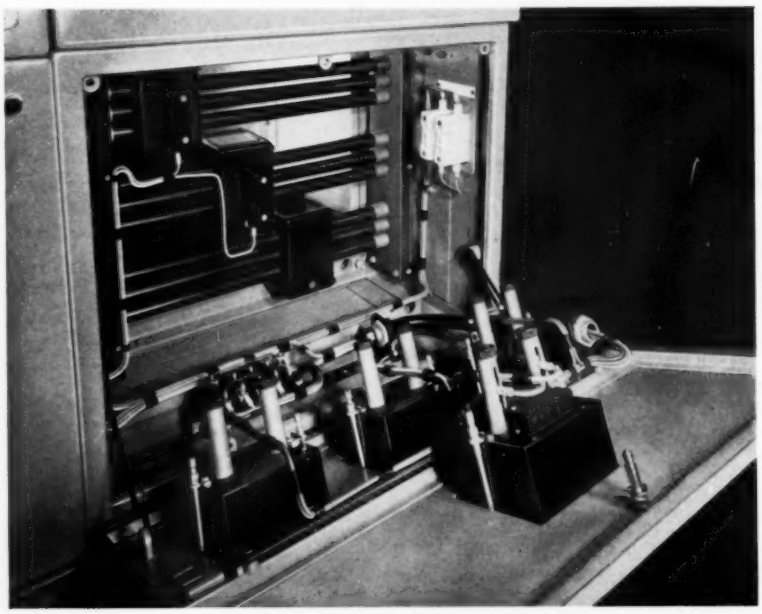


Fig. 6—A busbar chamber with hinged front cover lowered, showing position of potential fuses and fully shrouded busbars and terminals

Fig. 7—A typical 'English Electric' Superform sub-switchboard, incorporating on-load fuse-switches

reason why higher ratings may not be expected in the future. Fig. 5 shows a 750A 'English Electric' on-load Superform fuse-switch, which complies with all of the above requirements.

Beyond 750A, it is not usual for fuses to be used for feeder protection, unless they are backing up circuit-breakers, not because they are not adequate in themselves for protection, but because the size of controlling on-load switches is limited. The application is one for air circuit-breakers, which may also be used to provide remote or preference tripping facilities.

Operational safety

In ships with 220V d.c. auxiliaries the marine engineer has become accustomed to see 'live front' or open panel-mounted switchgear and distribution equipment. Although there is danger of electric shock at this voltage, it becomes much greater at 440V a.c. This is not fully appreciated by many marine engineers, and although adequate precautions are taken to make an a.c. switchboard 'dead-front', scant attention is paid to the rear. It is usual in both a.c. and d.c. ships to leave a passageway at the open rear of the main switchboard and prevent unauthorised access to it with doors at each end. It is then permissible for the rear of the switchboard to be 'live'. It is easy in a seaway for a person to be thrown, perhaps when holding a metal tool, against 'live' equipment. The only precaution normally taken against this is the provision of an insulated handrail. If it is thought necessary to maintain an open rear to the switchboard, and this is doubtful if isolating facilities are provided for the circuit-breakers it is essential that all busbars and connections be fully shrouded so that they cannot be touched either by operators or by falling tools. In view of the importance of the main busbar this precaution is advisable whether total enclosure is employed or not; Fig. 6 shows how this is carried out in 'English Electric' Superform switchboards.

It is essential that isolation facilities be provided for circuit-breakers to permit safe and proper maintenance of their many components, but this argument does not apply to fuse-switches of recent design. Modern double-break, fully-shrouded fuse-switches are not made withdrawable, because the circuit-breaking element, comprising non-deteriorating H.R.C. fuses, requires no maintenance. The occasional cleaning and greasing needed for the mechanism and contacts can be quickly carried out during the periodic overhaul of the ship.

The question of circuit isolation also arises in group-starter switchboards and there has been a tendency recently to provide swing-out or draw-out starters. If double-break fully insulated on-load switches are used, this is unnecessarily elaborate, because having opened the isolator, the starter cubicle is then 'dead' and the door may be opened. With modern contactors, there is then full access to all parts requiring maintenance. In ships, therefore, where conditions of vibration are frequently met, the additional contacts required for draw-out isolation tend to create more problems than they solve.

It is not only at the main switchboard that risk of electric shock exists ; an important contribution to the safety of personnel is made if all 'live' metal at the sub-switchboards and distribution fuseboards is individually enclosed and 'English Electric' Superform switchboards and Red Spot distribution fuseboard designs, examples of which are shown in Figures 7 and 8, represent the ultimate in this respect.

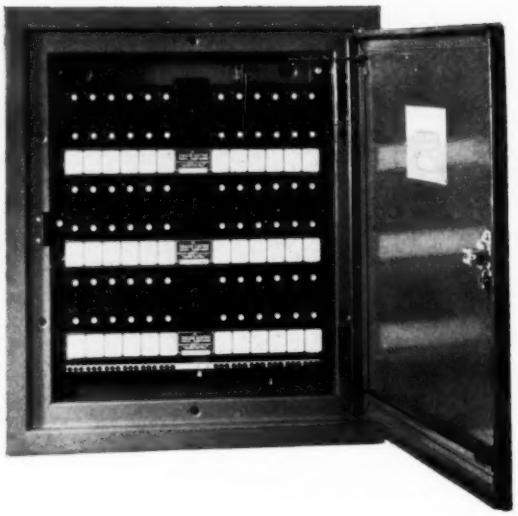


Fig. 8—An interior view of a flush mounting Red Spot 15A twelve-way, fully insulated fuse-distribution board

Computers as an Aid to Electric Mine Winder Design

by F. KILLORAN, A.M.I.E.E., Mining Division

THE APPLICATIONS for which the electrical design engineer has enlisted the aid of the universal digital computer cover a very wide field. On the one hand are the design calculations for large power transformers, and on the other performance figures, calculated from equivalent circuit values, for small rotating machines. Fig. 1 shows a computing service bureau available for work of this type employing 'English Electric' Deuce computers.

The control engineer, and the design engineer too, often have problems to solve on system performance which are difficult to put in mathematical terms or numerical values, or difficult and laborious to evaluate when put in such terms. Here the analogue computer, which can take many forms, plays an important role in component or system design. It has been recognised as an invaluable aid in servo system design, and with increasing automation its role will become more pronounced in this field.

One form of analogue computer is the network analyser, for the study of the effects of system faults on the supply network and generating stations, or the normal effect upon the network of new installations. The latter studies have been extremely important over recent years in determining the effects upon the supply network of feeding large d.c. reversing drives, such as mine hoists and steel rolling mills via mercury arc convertors. This has been necessary in order to be satisfied that such installations would not give rise to excessive

Fig. 1—The Central Computing Service Bureau of The English Electric Company at Kidsgrove. The DEUCE computer is here used for mine-winder design calculations

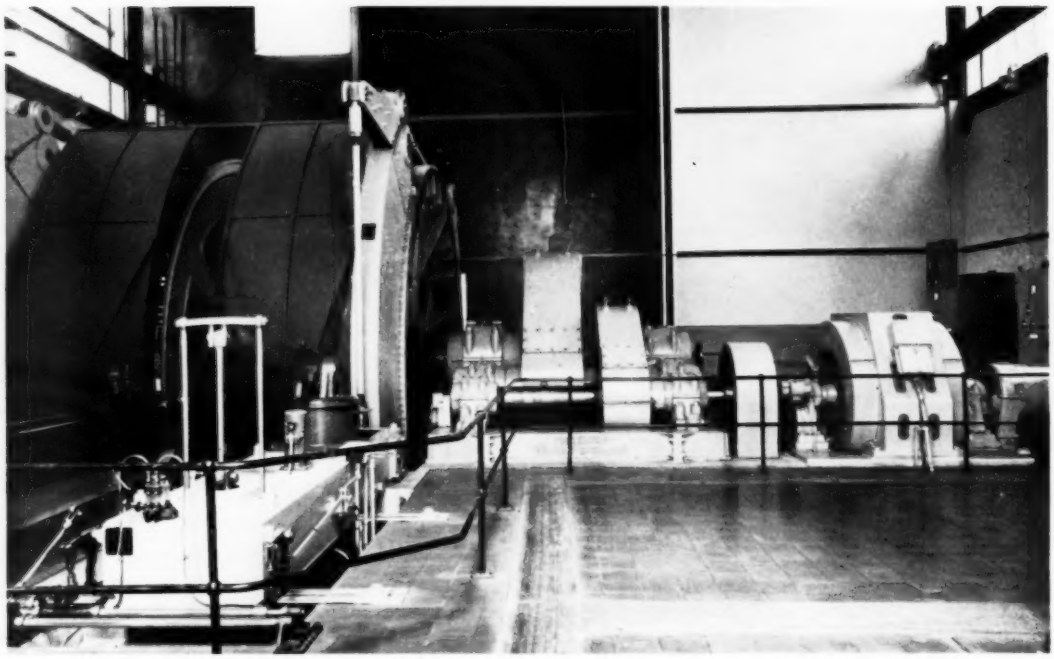


Fig. 2—A 1,000hp 3·3kV geared a.c. winder, fitted with dynamic braking equipment, at Bilston Glen Colliery No. 2 Shaft in the Lothians Area of the National Coal Board

voltage dips, to the detriment or annoyance of other users of electricity connected to the same feeder. On the other hand a Deuce computer is used to check the harmonic disturbances resulting from such applications.

The field, however, in which the analogue computer has achieved prominence is in the simulation of automatic control schemes to check stability and response in servo-controlled main drives, and more will be said of this later in the article with regard to electric mine winders.

From a design point of view the use of the digital computer has been for the most part confined to components, whereas analogue computers have had a very diverse range of application. There is no reason why the application of the digital computer should remain limited in this way, because wherever the application of electrical equipment is to follow a set pattern over a period of years, computer programmes can be developed to calculate the duty and select the machine and associated equipment. One major field of activity justifying its application in this way is that of the electric mine winder.

THE DIGITAL COMPUTER

The winder specification

Fig. 2 shows a typical modern electric mine winder house. The main requirements to be satisfied in any such winder installation are those of hoisting the specified hourly output, and of lowering or hoisting men to or from the underground station safely. The principal duty of hoisting coal or ore should normally determine the size of the winder motor for continuous operation, but a number of special duties often have normally to be performed and the capability of the machine to do these needs to be checked. These special duties may include any or all of the following : raising heavier-than-normal loads over short periods of time ; lowering heavy pieces of machinery for use underground ; and running over

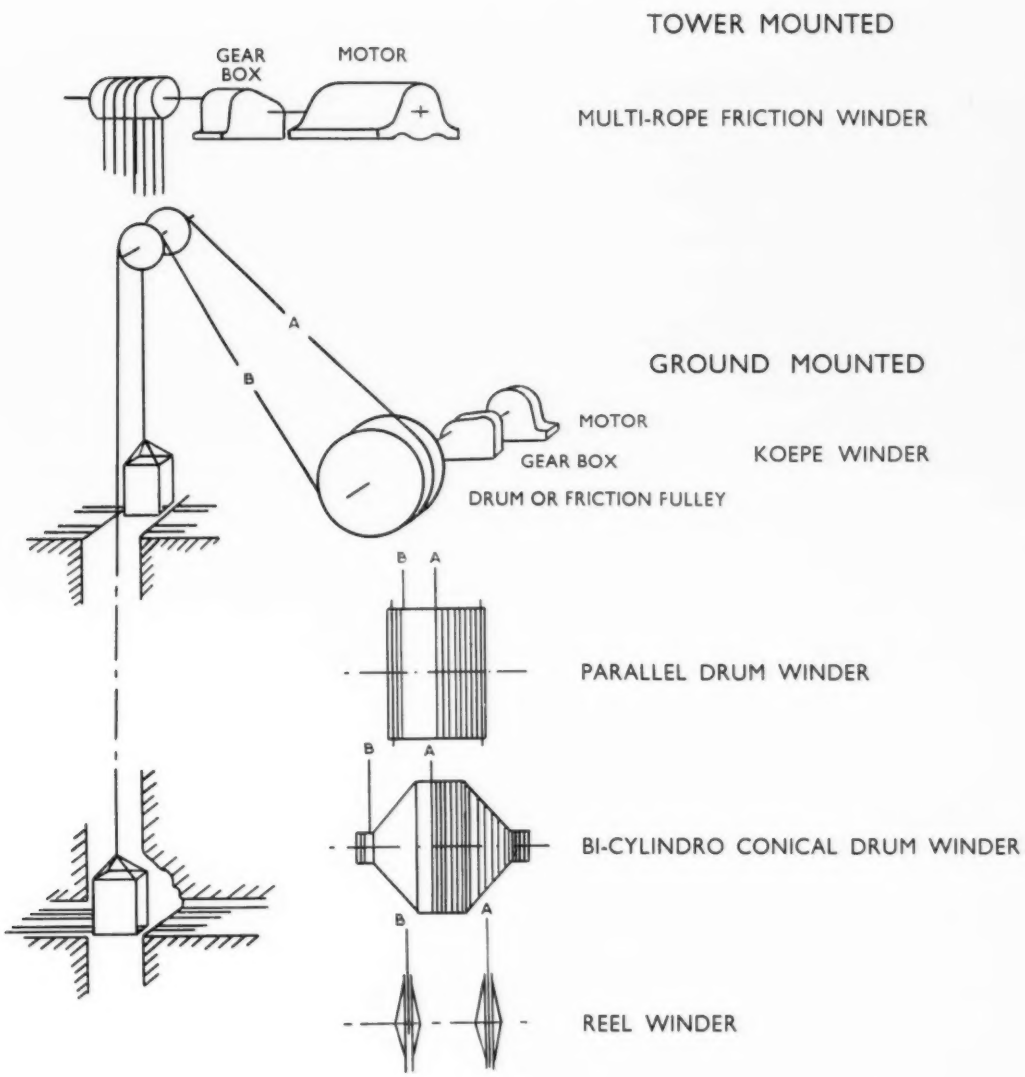


Fig. 3—Types of mine winder

comparatively long periods at very low speed, for rope changing and rope and shaft inspections. These special duties may affect the peak torque requirements of the machine and of associated supplies.

The two main types of winder called for today are the friction and parallel drum designs. These two types may be further subdivided, the friction winder being either multi-rope or single rope (Koepe), with the friction pulley either ground or tower mounted. The parallel drum may be specified as a single unit, or as a double unit with a clutch between for the convenience of operating between different levels with two conveyances. The

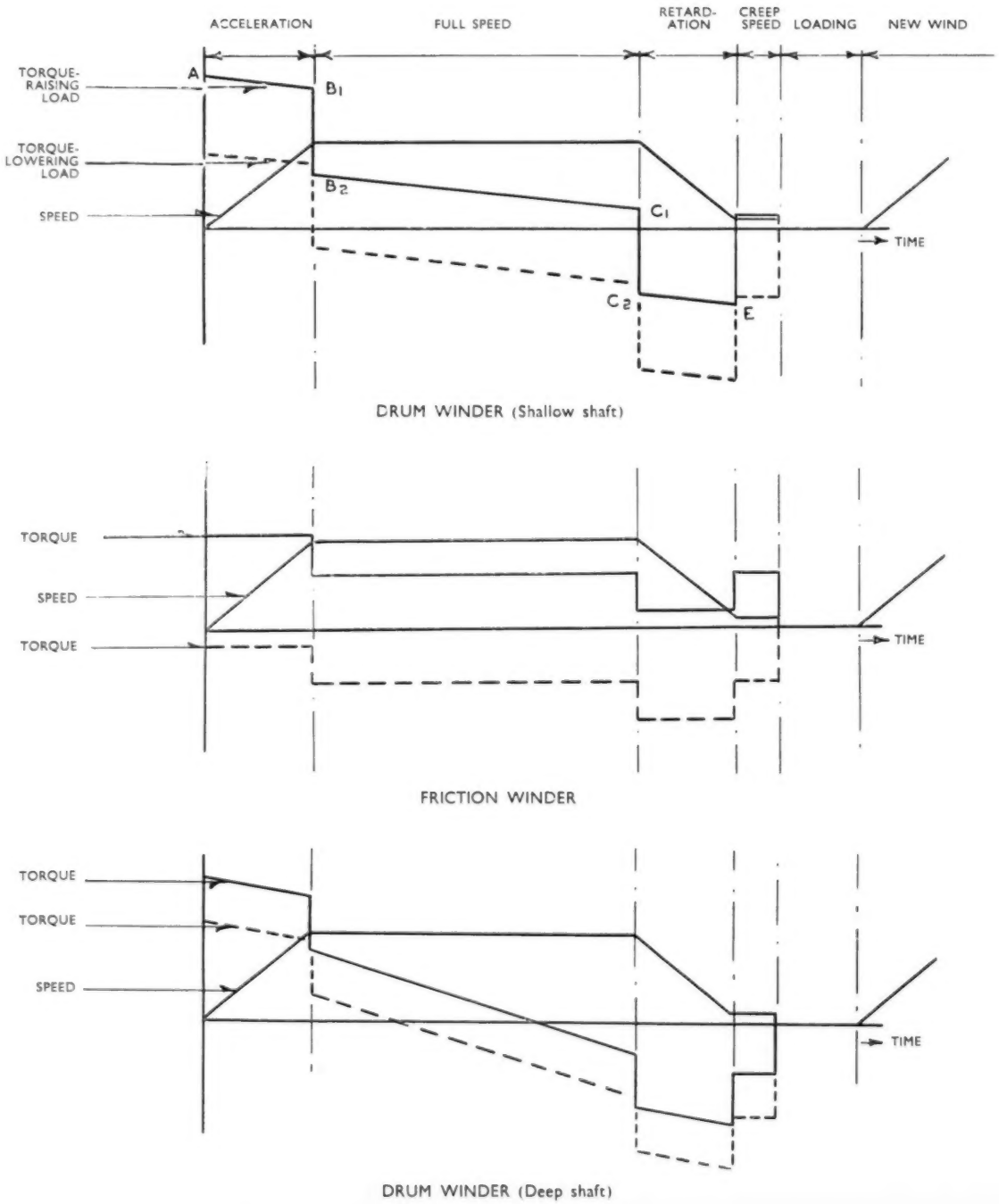


Fig. 4—Typical mine winder duty cycles

parallel drum winder may also be specified with or without a balance rope, its inclusion reducing the peak demand on the motor and supply.

Other types of winder such as the reel and the bi-cylindro-conical drum are also available as a means of reducing the peak torque requirements ; these are rarely called for today, and were of most value in the days of the steam driven winder where the prime mover itself had to be designed for the peak torque requirements. The electric motor with its inherent overload capacity does not need these artificial means of peak torque limitation to the same extent. Although their use would lead to some reduction in the size of motor required for a particular duty and to some reduction in running costs, such savings would have to be equated against the increased capital and recurring cost of the flat rope necessitated by the reel, or against the increased capital cost of the bi-cylindro-conical drum.

Diagrammatic sketches of the various types of winder are shown in Fig. 3.

Two other factors having a major influence on the winder duty cycle are normally determined by the prospective customer before submitting the enquiry to the electrical manufacturer. These are the payload or portion of the required hourly output conveyed per wind, and the decking time or period of time required for loading and unloading the conveyances. These two figures will have been determined from shaft cross-sectional area, and shaft bottom and top loading and unloading arrangements. In general, for a fixed hourly output from a given depth the lighter the payload, or the longer the decking time, the larger will be the horsepower of the winder motor, because of the increased speeds and acceleration rates necessary to achieve the output.

Being thus provided with type of winder, hourly output, shaft depth, conveyance weight, payload, and decking time—plus certain limits on dimensions for the headgear and winder house layout—the winder design may be optimised.

Duty cycles

Duty cycles likely to be encountered for the various types of winder drive are shown in Fig. 4. While these cycles vary considerably in detail they all comprise five basic periods :—

(i) A period of constant or graded acceleration from rest to full speed.

(ii) A full-speed running period.

(iii) A period of constant retardation from full speed down to creep speed.

(iv) A short period on creep speed for final positioning of the conveyances.

(v) A period to load and/or unload the conveyances.

Final stopping at the end of period (iv) is achieved by the application of mechanical brakes ; similarly, before the start of period (i) torque sufficient to hold the load must be produced by the winder motor before the mechanical brakes are released to allow motion to take place. Period (v) may involve additional movement of the conveyances, if they are multi-deck cages arranged to be loaded and/or unloaded consecutively.

The optimum cycle

What is the optimum cycle, and what should be looked for in determining this? The higher the rate of acceleration the greater the peak torque the winder motor will have to develop, but the lower the top speed will be to achieve the required output. A well designed motor for frequent reversing duty will be capable of producing a peak torque over the normal accelerating periods of approximately twice its continuous or normal rated torque. This will therefore set a limit on the acceleration possible, but in addition a rate of 3 ft/sec^2 is the accepted limit, particularly where man-riding is performed to the same speed/time cycle as used for minerals. Shaft maintenance costs would appear to bear some relationship to conveyance speed ; the lowest possible speed is therefore very desirable from this point of view. Also, the higher the motor speed the cheaper it will be for a given output, but the higher the gear ratio for a given drum or friction pulley r.p.m. The highest gear ratio acceptable for a single reduction unit is 10 : 1 in the U.K. and not generally more than 12 : 1 elsewhere. Therefore, a motor speed necessitating a higher reduction than this may mean the adoption of double reduction gearing, with a consequent increase in capital cost and

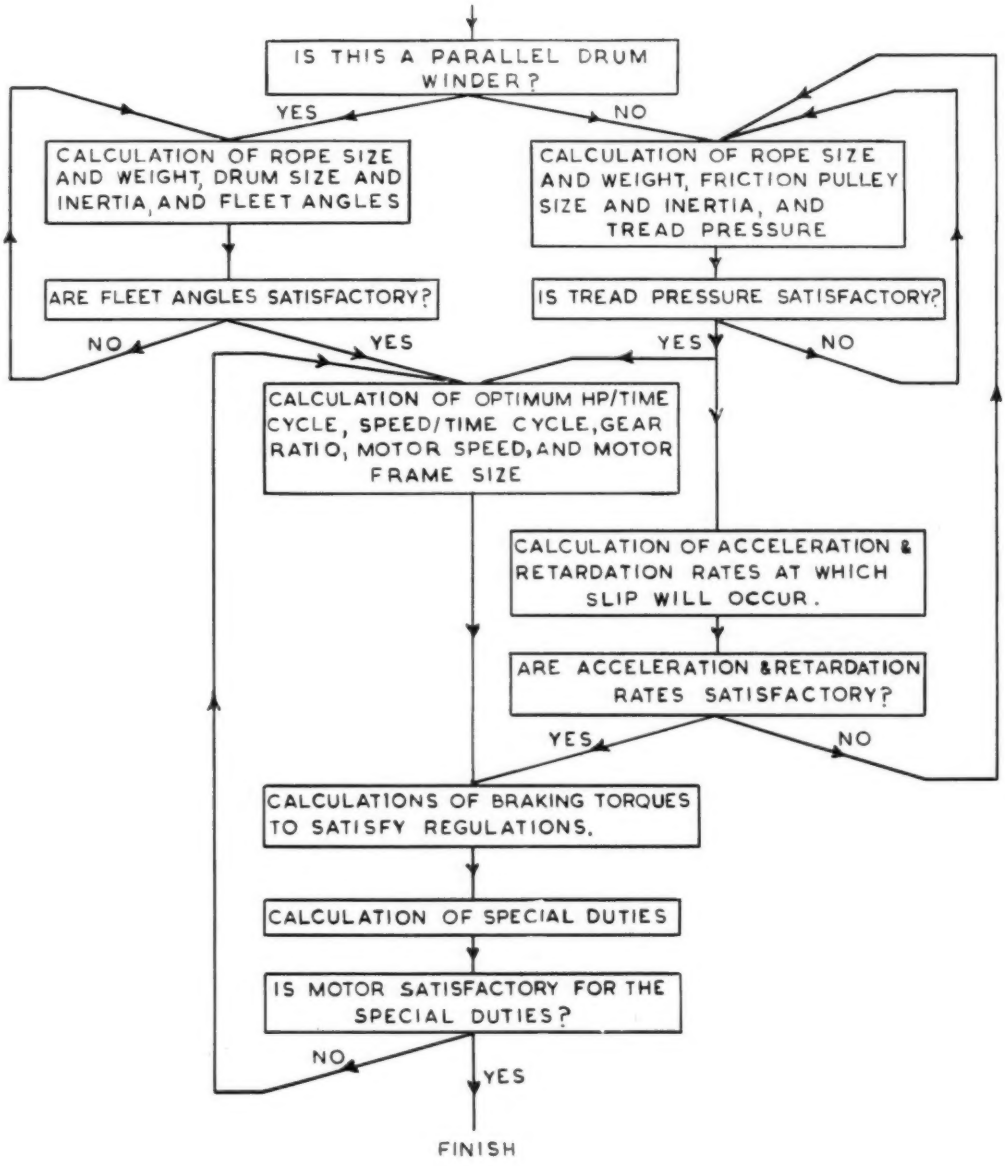

IS THIS A PARALLEL DRUM WINDER?
YES
NO
CALCULATION OF ROPE SIZE AND WEIGHT, DRUM SIZE AND INERTIA, AND FLEET ANGLES
CALCULATION OF ROPE SIZE AND WEIGHT, FRICTION PULLEY SIZE AND INERTIA, AND TREAD PRESSURE
ARE FLEET ANGLES SATISFACTORY?
IS TREAD PRESSURE SATISFACTORY?
NO
YES
YES
NO
CALCULATION OF OPTIMUM HP/TIME CYCLE, SPEED/TIME CYCLE, GEAR RATIO, MOTOR SPEED, AND MOTOR FRAME SIZE
CALCULATION OF ACCELERATION & RETARDATION RATES AT WHICH SLIP WILL OCCUR.
ARE ACCELERATION & RETARDATION RATES SATISFACTORY?
YES
NO
CALCULATIONS OF BRAKING TORQUES TO SATISFY REGULATIONS.
CALCULATION OF SPECIAL DUTIES
IS MOTOR SATISFACTORY FOR THE SPECIAL DUTIES?
NO
YES
FINISH

Fig. 5—The sequence of computer calculation in designing a mine winder

gearing losses. The higher speed of the winder motor with its resultant saving in machine cost might, therefore, be offset by an increased output being required and increased costs for the gearing. Higher motor speeds for a given output also lead to reductions in the cost of couplings, and of dynamic braking equipments in the case of a.c. drives.

The general rule may therefore be formulated that the optimum design will be that which, by suitable adjustment of acceleration and hence speed, gives the minimum horsepower for the winder motor at which the peak horsepower during the acceleration period does not exceed twice this minimum value. The speed of the winder motor should be the highest possible for single reduction gearing to be incorporated between the winder motor and the drum or friction pulley.

The calculations

Fig. 5 is a 'flow diagram' of the calculations involved in the design of a winder. It will be seen that first considerations in the calculations are mechanical, and are concerned with the selection of rope size, drum or friction pulley diameter, and with the obtaining of a satisfactory layout of the equipment within the limiting dimensions specified by the customer. The rope size will be influenced by the factors of safety and/or capacity factors applicable in the country for which the equipment is destined to operate. Drum diameter may be dependent upon whether multi-layer coiling of the rope is acceptable to the prospective customer, or if single layer coiling is the choice. Deep shaft winders will almost certainly necessitate the multi-layer arrangement. In the case of friction winders the drive is obtained by friction between the rope and the pulley over which it passes. Here the question to be settled, once the minimum pulley diameter has been determined from the specified rope-to-pulley-diameter ratio, is that the tread pressure is within the specified limit. In the case of tower-mounted friction winders it is also extremely worthwhile endeavouring to match the pulley diameter to the conveyance centres and hence avoid the inclusion of deflector sheaves with their added inertia to the system. From the results of the above work, rope weight per foot, drum and sheave dimensions and inertias, and angle-of-lap in the case of friction winders, are all used in the next stage of the calculations, which is to determine the best horsepower/time cycle for the winder. This involves the determination of the horsepower at the cardinal points of the cycle and the resultant r.m.s. horsepower, the acceleration time being so varied as to produce the relationship between r.m.s. and peak horsepowers mentioned earlier. Considering Fig. 4 again, the six cardinal point values denoted as A, B^1, B^2 will be given by the following expressions :

$$HP_{.A} = \frac{v}{550}\left(\pm W_L + W_f + dwx + \frac{W_E v}{gt_a}\right) \quad \ldots\ldots(1)$$

$$HP_{.B1} = \frac{v}{550}\left(\pm W_L + W_f + (d - vt_a)wx + \frac{W_E v}{gt_a}\right) \quad \ldots\ldots(2)$$

$$HP_{.B2} = \frac{v}{550}(\pm W_L + W_f + (d - vt_a)wx) \quad \ldots(3)$$

$$HP_{.C1} = \frac{v}{550}(\pm W_L + W_f \quad (d - vt_r)wx) \quad \ldots(4)$$

$$HP_{.C2} = \frac{v}{550}\left(\pm W_L + W_f \quad (d - vt_r)wx - \frac{W_E v}{gt_r}\right) \quad \ldots\ldots(5)$$

$$HP_{.E} = \frac{v}{550}\left(\pm W_L + W_f \quad dwx - \frac{W_E v}{gt_r}\right) \quad \ldots(6)$$

where v = maximum velocity of conveyances (ft/sec)

W_L = payload (lb)

W_f = allowance for friction (lb)

d = winding distance (ft)

w = weight of winding rope (lb/ft)

W_E = effective weight of all moving and rotating parts referred to the rope

g = acceleration due to gravity (32·2 ft sec^2)

t_a & t_r = acceleration and retardation times respectively (sec)

x = rope out-of-balance indicator—usually 1 or 0.

The continuous rating of the motor will be that horsepower which would produce the same heating as that produced on the operating cycle. This is known as the r.m.s. horsepower and is given by the following expression, the denominator of which has been derived empirically :—

$$R.M.S.\ HP. = \sqrt{\frac{(A^2 - B_1^2 - AB_1)\frac{t_a}{3} + (B_2^2 + C_1^2 + B_2C_1)\frac{t_s}{3} + (C_2^2 - E^2 - C_2E)\frac{t_r}{3}}{\frac{t_a}{3} + t_s + \frac{t_r}{3} + \frac{t_d}{3}}} \quad \ldots\ldots(7)$$

where A, B, etc. = hp. values at cardinal points

t_s = full speed motor running time (sec)

t_d = decking time (sec)

It will be appreciated that expressions (1) to (6) above apply particularly to direct-coupled drives and that where gearing is involved the horsepower to accelerate or retard the motor must be separated from the $\frac{W_E V^2}{550 g t_a}$ value, the remainder being multiplied by the appropriate efficiency factor to account for losses in the gears, and the motor acceleration or retardation horsepower then again added to the resultant (algebraically). Also that the out-of-balance indicator or factor x will have the value I where the winder is not fitted with a balance rope, and O where a balance rope is fitted equal in weight per unit length to that of the winding rope. In the latter case any variation from equality will mean the factor is of fractional value and varies in sign dependent upon whether the balance rope is heavier or lighter than the winding rope.

The value of x will be given by the expression

$$x = \frac{W_{WR} - W_{SR}}{W_{WR}},$$

where W_{WR} = weight per unit length of winding rope, and

W_{SR} = weight per unit length of balance rope.

In the case of friction winders when the duty cycle has been optimised from the above considerations it is essential to check that cyclic acceleration and retardation rates can be obtained with sufficient margin between these values and values which would cause the winding rope to slip on the friction pulley—and also that the regulations covering mechanical braking can be satisfied. The following expressions will give the maximum acceleration and retardation rates beyond which the rope would slip on the pulley.

Maximum permissible acceleration when raising out-of-balance load

$$= \frac{e^{\mu\theta}\left(1 - \frac{W_F}{Q}\right) - \left(\frac{P}{Q} + \frac{W_F}{Q}\right)}{e^{\mu\theta} A + B} g \quad \ldots\ldots(8)$$

Maximum permissible retardation when raising out-of-balance load

$$= \frac{e^{\mu\theta}\left(\frac{P}{Q} + \frac{W_F}{Q}\right) - \left(1 - \frac{W_F}{Q}\right)}{e^{\mu\theta} B + A} g \quad \ldots\ldots(9)$$

Maximum permissible acceleration when lowering out-of-balance load

$$= \frac{e^{\mu\theta}\left(\frac{P}{Q} - \frac{W_F}{Q}\right) - \left(1 + \frac{W_F}{Q}\right)}{e^{\mu\theta} B + A} g \quad \ldots\ldots(10)$$

Maximum permissible retardation when lowering out-of-balance load

$$= \frac{e^{\mu\theta}\left(1 + \frac{W_F}{Q}\right) - \left(\frac{P}{Q} - \frac{W_F}{Q}\right)}{e^{\mu\theta} A + B} g \quad \ldots\ldots(11)$$

where P = total suspended load on most heavily loaded side

Q = total suspended load on lightest loaded side

(Note :—The total suspended load should include the rope.)

g = 32·2

e = 2·718

μ = coefficient of friction between rope and pulley

θ = angle of contact between rope and pulley expressed in radians

W_F = estimated shaft friction load

The factors A and B vary according to the type of friction winder under consideration. For ground mounted friction winders the substitutions are :—

$$A = 1 + \frac{W_S}{Q}$$

$$B = \frac{P}{Q} + \frac{W_S}{Q}$$

where W_S = effective weight of rope sheaves. Other substitutions are available for the different possible arrangements of tower mounted equipment.

The regulations on mechanical brakes which have to be satisfied are as follows :—

The service level of braking shall (i) exert a braking torque on the pulley which is at least 2·5 times the static torque on the pulley caused by the maximum difference between the loads on the winding rope : and (ii) produce a retardation of at least 5 ft/sec² when there is the maximum difference between the loads on the winding rope, and the heavier load is descending.

The emergency level of braking shall (i) produce the maximum braking torque on the friction pulley which would not cause the rope to slip if the coefficient of friction between the rope and the pulley is 0·2 when any loads up to the maximum specified are being raised or lowered : and (ii) produce a retardation of at least 3 ft/sec² when there is the maximum difference between the loads on the winding rope, and the heavier load is descending.

Where regulations such as the ones just enumerated with respect to mechanical braking are inserted as instructions into the computer programme it will be seen that the machine becomes much more than a calculator : it becomes, in fact, an infallible critic of what is right or wrong, or of what will work or will not work. Any experience can be interpreted into regulations of what must or must not be done in a particular instance and can therefore be utilised by the machine in a selective programme.

Finally, to enable the Deuce computer to complete the calculations it is necessary that the electric motor information, normally available to the applications engineer, shall be stored within the computer for it to make the required selection at the appropriate point in the calculations. The range of this store is for voltages up to 11kV for a.c. machines, and speeds up to 600 r.p.m. for both a.c. and d.c. machines. The essential details of the selected motor, so far as the winder calculations are concerned,

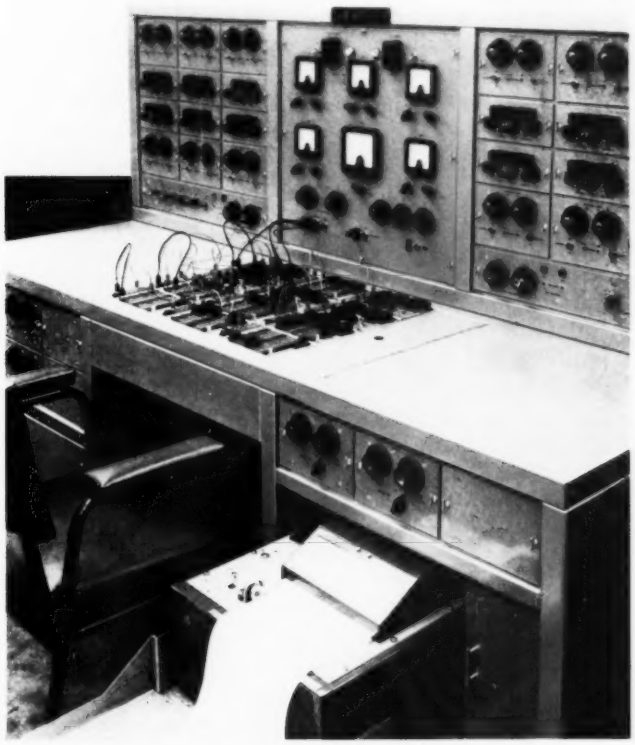


Fig. 6—The 'English Electric' KAE1 analogue computer

are its inertia, and peak and r.m.s. horsepower values: these, together with the frame size, are used by the computer and specified in the results.

winder shall be made to operate to this prescribed cycle. The choice of course lies between manual and automatic control, with the prospective customer making the decision before submission

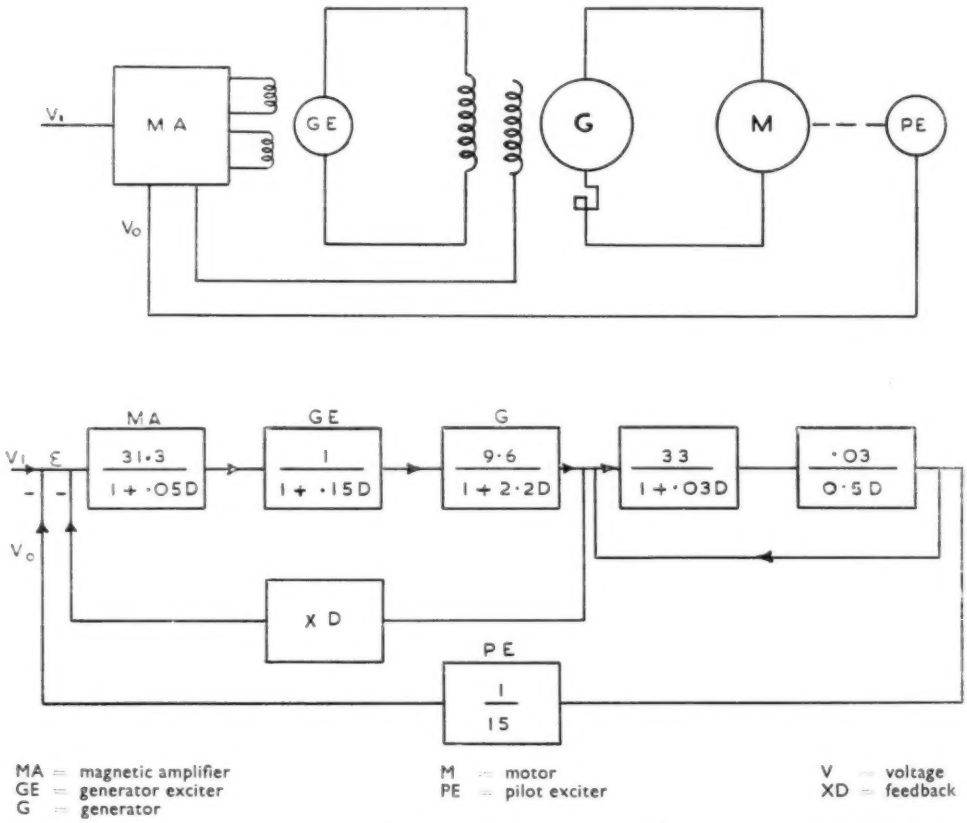


Fig. 7—Simplified schematic diagram (above), *and equivalent block diagram* (below), *of a magnetic-amplifier-controlled Ward-Leonard equipment*

Table 1 gives computer and hand calculated results for a typical enquiry, with the former showing to advantage where differences do exist. It will be appreciated that such results are obtained from the computer in a matter of minutes, whereas an engineer may have taken as many days.

Shaft utilisation and safety

Having determined the optimum running cycle for the winder it must next be decided how the

of the enquiry or asking for prices for the alternatives. But factors taken into consideration in arriving at this decision are worth considering.

(*i*) *Shaft utilisation*—If there is a continuous supply of coal or ore available to be hoisted to the surface, it is extremely important that the winder shall run to the utmost of its capacity. This can only be achieved by fully automatic operation, or realised to a large extent by semi-automatic operation.

(*ii*) *Manpower*—Fully or semi-automatic operation will lead to a reduction in manpower requirements, providing all duties can be carried out under the mode of operation chosen.

(*iii*) *Regulations*—Where regulations do not allow for men to be conveyed under automatic control, (*ii*) becomes a very minor consideration where a winder must be used for this purpose.

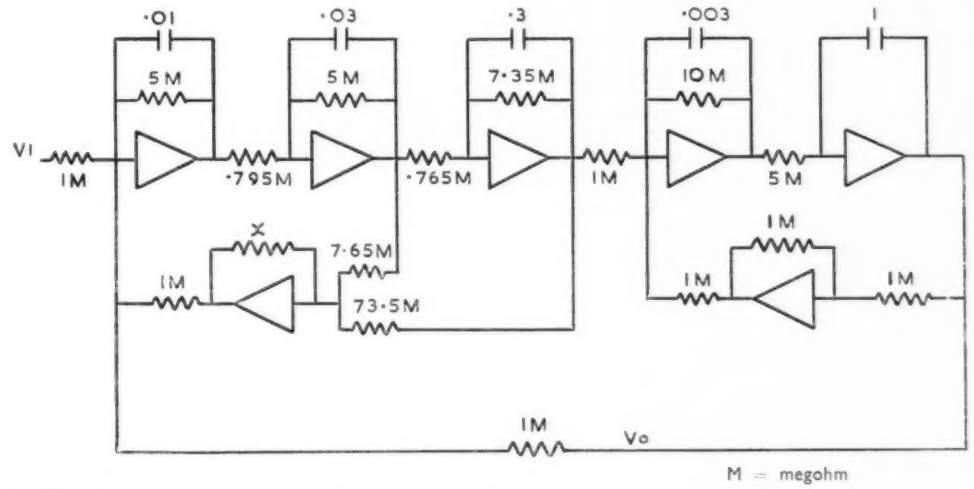


Fig. 8—The electrical analogue corresponding to Fig. 7

TABLE 1

TYPICAL RESULTS FOR MINE WINDER INVESTIGATION

Winder Specifications :—

Output	250 tons/hr
Depth of wind	1,400 ft
Payload	4 tons
Drum diameter	14 ft
Drum and gear inertia	105,000 lb. ft/sec
Effective weight of headsheaves	15,800 lb
Weight of each conveyance	9,680 lb
Weight of tubs/conveyance	5,152 lb
Decking time	13 sec

		Hand calculations	Computer calculations
The cardinal point values of Fig. 5	A	3,200	3,160
	B_1	2,970	2,925
	B_2	1,278	1,278
	C_1	470	469
	C_2	−1,135	−1,094
	E	−1,350	−1,307
R.M.S.		1,914	1,884
R.M.S./peak		·598	·596
Motor frame size		LS 126/910	LS 126/810
Rope speed		43·2 ft/sec	43·2 ft/sec
Motor speed		570 r.p.m.	570 r.p.m.
Gear ratio		9·67 : 1	9·67 : 1
ta=tr		12 sec	12 sec
ts		20·6 sec	20·6 sec

(*iv*) *Special duties*—These have been mentioned above under the heading 'The winder specification'. If such duties predominate in the total time of operation, then the winder may be designated a 'service winder' and there is very little case to put forward for anything other than straight manual control.

(*v*) *Safety*—Any winder in the U.K. running at speeds in excess of 12 ft/sec is, by Mining Regulations, fitted with an 'automatic contrivance' which trips the power supplies and applies the mechanical brakes if (*a*) the winder exceeds the permitted speed by more than a small percentage at any point in the wind, and (*b*) moves past the normal upper or lower limits of the wind. This ensures that the system is protected against the worst possible accident but an overspeed trip at 40-50 ft/sec is not an experience to be enjoyed by the riders, even though it is better than crashing on to the timber baulks at the bottom of the shaft. There are therefore grounds for the use of control schemes having means of enforcing retardation at a designed rate, or preventing overspeed by reducing the

available power, or applying electrical braking to hold the load to a given speed.

THE ANALOGUE COMPUTER

Having taken all the above factors into consideration a choice may then have to be made of some form of automatic operation. For this work an analogue computer is used (Fig. 6). System gain is the first matter for determination, and this must be sufficiently high to ensure that, with the specified payload variations, little or no variation is apparent in the cyclic time of the winder. The next question to be answered is the degree of stabilising feedback necessary to obtain a reasonable system response, i.e. to ensure that the response is not so fast as to cause excessive overshoot of the controlled variable, nor yet so slow in correcting system errors as to cause variations in the cyclic time for the winder. A simplified schematic diagram of one mine winder scheme is shown in Fig. 7 with the equivalent block diagram. The analogue circuit to set up the problem on the computer is shown in Fig. 8. The circuit comprises the magnetic amplifier (MA), the generator exciter (GE), generator (G), motor (M) and the pilot exciter (PE). The reference quantity is the signal voltage V_1, while the controlled variable is the output signal V_0 obtained from the pilot exciter which is mechanically coupled to the winder motor. The pilot exciter is provided with a constant field, hence the feedback V_0 is proportional to the speed of the winder motor. The transfer functions of the various elements are shown in the block diagram, i.e. the term relating the output quantity to the input quantity, and this may involve amplification and time delays. The transient or stabilising feedback xD is obtained from an auxiliary field on the generator, and the magnitude of this term will be determined by experiment on the analogue computer to obtain a satisfactory response.

A GREATER DEGREE of optimisation in the design of mine winders is possible when there is close contact between civil, mechanical and electrical engineers at the preliminary design stage. Computers are infallible machines, providing the correct instructions are given to them, and fed with mathematical processes and designers' experience, they will produce the best answer to the problem under consideration.

THE
ENGLISH ELECTRIC
COMPANY LIMITED

ALLIED AND ASSOCIATED COMPANIES

D. Napier & Son, Ltd.
and its Subsidiaries

Marconi's Wireless Telegraph Company, Ltd.
and its Subsidiaries

The Marconi International Marine Communication Company, Ltd.
and its Subsidiaries

The Vulcan Foundry Ltd.

Robert Stephenson & Hawthorns Ltd.

English Electric Export & Trading Co., Ltd.

English Electric Valve Co. Ltd.

Canadian Marconi Company.

John Inglis Co., Limited, Toronto.

English Electric Canada,
(A division of John Inglis Co. Ltd.)

The English Electric Company of South Africa (Proprietary), Ltd.

The English Electric Company (Central Africa) (Private), Ltd.

English Electric de Venezuela, C.A.

The English Electric Company of India (Private), Ltd.

The English Electric Company of Australia Pty. Ltd.

The English Electric Company of New Zealand Ltd.

English Electric Espanola S.A.

English Electrica de Portugal Limitada.

English Electric Marconi Argentina S.R.L.

Associated Transistors Ltd.

British Aircraft Corporation Limited
and its Subsidiaries

The English Electric, Babcock & Wilcox and Taylor Woodrow Atomic Power Construction Co. Ltd.

PRODUCTS OF THE ENGLISH ELECTRIC COMPANY LIMITED

Generating Plant—Steam, Hydraulic, Atomic, Gas Turbine or Diesel. Transformers, Rectifiers, Switchgear and Fusegear. Electric Motors. Industrial Electrification. Welding Equipment. Electric and Diesel-electric Traction. Marine Propulsion and Auxiliaries. Aircraft. Aircraft Equipment. Data Processing Equipment. Industrial Electronic Equipment. Meters, Relays and Instruments. Domestic Electrical Appliances.

Printed in Great Britain by Straker Brothers Limited, London, E.C.2.